AD 611251

WT-792

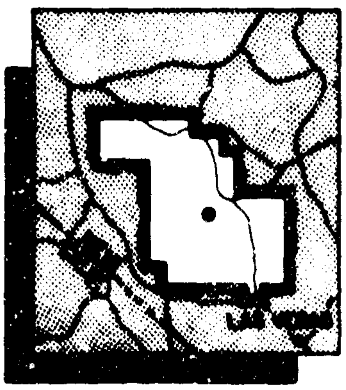
Operation UPSHOT-KNOTHOLE

NEVADA PROVING GROUNDS

March - June 1953

Project 21.2

EFFECTS OF AN ATOMIC EXPLOSION ON TWO TYPICAL TWO-STORY-AND-BASEMENT WOOD-FRAME HOUSES



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FEDERAL CIVIL DEFENSE ADMINISTRATION
WASHINGTON D.C.

WT-792

Report to the Test Director

EFFECTS OF AN ATOMIC EXPLOSION ON TWO TYPICAL TWO-STORY-AND-BASEMENT WOOD-FRAME HOUSES

By

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Federal Civil Defense Administration
Washington, D. C.
September 1953

ABSTRACT

Two typical two-story frame houses, without utilities, were located at 7500 and 3500 ft from Ground Zero of a 16.4-kt bomb exploded at 300 ft above the ground. Exposure of the houses was for public demonstration purposes and to study the gamma-radiation scatter and the effects of thermal radiation and blast on each house.

Both houses were furnished, and, in each, department-store mannequins were placed in the dining and living rooms. Film badges to measure gamma radiation were placed in layers throughout the house at 7500 ft and in the basement of the house at 3500 ft. Visual inspection and photography were utilized to study thermal-radiation and blast effects.

Because of the heavy fall-out of radioactive material in the area surrounding both houses and the resulting delay in recovering badges, initial gamma-radiation quantities could not be determined.

On the house at 7500 ft, only the light-gray painted shutters on the side facing the detonation were scorched from thermal radiation. Mannequins were thrown about, and some were severely damaged by flying glass and debris. The house was badly damaged inside, although, with the exception of broken windows and doors, the exterior appeared almost unchanged. When viewed from the side, a slight cant to the rear was noticeable, roughly 1 to 2 in. at the eave line. About 35 per cent of the first-floor joists under the kitchen, dining room, and living room was broken or split near the bottom edges; the damage generally started at a knot. The second-floor framing appeared undamaged. All but one of the roof rafters in the front facing the blast were broken at midspan and pushed down slightly at the ridge.

All exterior woodwork on the front of the house at 3500 ft was charred from thermal radiation, but no fire resulted. Mannequins were generally broken and trapped in the debris. The blast demolished this house. The first story disintegrated, allowing the badly damaged second story to settle down on the first floor. The roof broke into three sections and came to rest on the ground at three different locations. The chimney was broken into large sections and lay on the ground at a 45° angle to the rear. Other remaining sections of the house were moved off the basement walls and away from the blast.

A conventional wood-frame house will be severely damaged at an overpressure of 2 psi and will be destroyed at 5 psi.

Damage to mannequins indicates that human beings without shelter in the same locations would have been injured in the far-range house and either killed or seriously injured in the near house by the effects of blast.

Damage to the far-range house could have been reduced by improved window and door design; by the use of light timber roof trusses, stronger rafters, or intermediate rafter support on attic partitions; by selecting and placing floor joists to avoid knots near the tension edges; by using steel joist hangers to support the ends of the header joists; by doubling trimmers at the fireplace; by stronger or more closely spaced wall studs; and by the use of materials that are less frangible and more elastic than plasterboard and plaster.

Conventional methods of wood-frame house construction, even with the best of materials and workmanship, cannot provide sufficient strength to resist pressures such as existed at the

near range. New designs would have to be prepared in order to provide a house to resist these pressures.

Future tests of houses should be made to measure reflected pressures on the front face and pressures inside and to check more blast-resistant designs of wood construction.

ACKNOWLEDGMENTS

L. A. Darling Co. of Bronson, Mich., loaned, without charge to the Federal Civil Defense Administration (FCDA), all department-store mannequins used in the houses.

North American Van Lines, Inc., transported mannequins and surplus government furniture to and from Las Vegas, Nev., without cost to FCDA.

The Atlas Trucking Company of Las Vegas, Nev., as a public service, hauled mannequins and furniture to and from the Nevada Proving Grounds, in addition to supplying some of the furniture.

The J. C. Penney Co. of Las Vegas, Nev., through the National Retail Dry Goods Association, donated clothing and dressed all mannequins used in this test.

The film and film holders used in the measurement of the gamma-radiation dose were supplied by the Radiation Instruments Branch of the U. S. Atomic Energy Commission, and the films were processed and read at the National Bureau of Standards.

Jack C. Greene of the Health and Welfare Division, FCDA, assembled and supervised the placing of badges and interpreted the film readings.

Bernis E. Brazier of Salt Lake City, Utah, representing the American Institute of Architects (AIA) as a member of the Evaluation Team, assisted in preparing the houses for the test, studying and evaluating damage, and reviewing this report.

Benjamin C. Taylor, Director of the Technical Division of the Engineering Office, FCDA, and a member of the Evaluation Team, gave valuable assistance in assessing the damage, suggesting means of making wood-frame houses more blast-resistant, and reviewing this report.

Gilbert D. Spindel, formerly with the FCDA, designed and prepared the plans and specifications for the houses.

Frederic A. Pawley, Research Secretary of the AIA, served as a consultant with regard to the design of the dwellings being representative of the average American home of this type.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

Two wood-frame two-story-and-basement houses were constructed at 3500 and 7500 ft from Ground Zero at the Nevada Proving Grounds and exposed to a 16.4-kt atomic bomb exploded at an altitude of 300 ft. The purposes of the test were (1) to demonstrate to invited State and Civil Defense officials and to the American people, through the press, television, and motion pictures, the effects of an atomic explosion on one common type of American home and (2) to study the gamma-radiation scatter and the effects of thermal radiation and blast on such houses.

1.2 BACKGROUND

The effects of an atomic explosion on the buildings and homes in Nagasaki and Hiroshima, in Japan, have been surveyed, and the results have been published elsewhere.[1-4]

Japanese methods of home construction are different from those used in this country. In spite of this, it is the opinion of a "group of highly qualified architects and engineers who surveyed the damage . . . that the resistance to blast of American residences in general would not be markedly different from that observed in these cities."[2] However, since the bomb size and height of burst were different in this test from those in Japan, no attempt has been made to correlate damages.

1.3 TEST HOUSES

Specifications for the test houses are given in Appendix A. Figures 1.1 to 1.8 present selected frames from a motion picture showing the effects of heat and blast on the house at 3500 ft from Ground Zero during the test. Figure 2.1 shows the house at 7500 ft from Ground Zero before the test, and Figs. 2.2 to 2.36 the results after the test. Figure 2.37 shows the house at 3500 ft before the test, and Figs. 2.38 to 2.57 the results after the test.

1.4 INSTRUMENTATION

No funds were available for instrumentation. Still- and motion-picture photography were utilized along with visual inspection to observe the effects of blast and heat. Gamma-radiation film badges were placed in three horizontal layers in the basements of the houses. Badges located inside at basement walls were attached to the cinder blocks by nailing through adhesive-

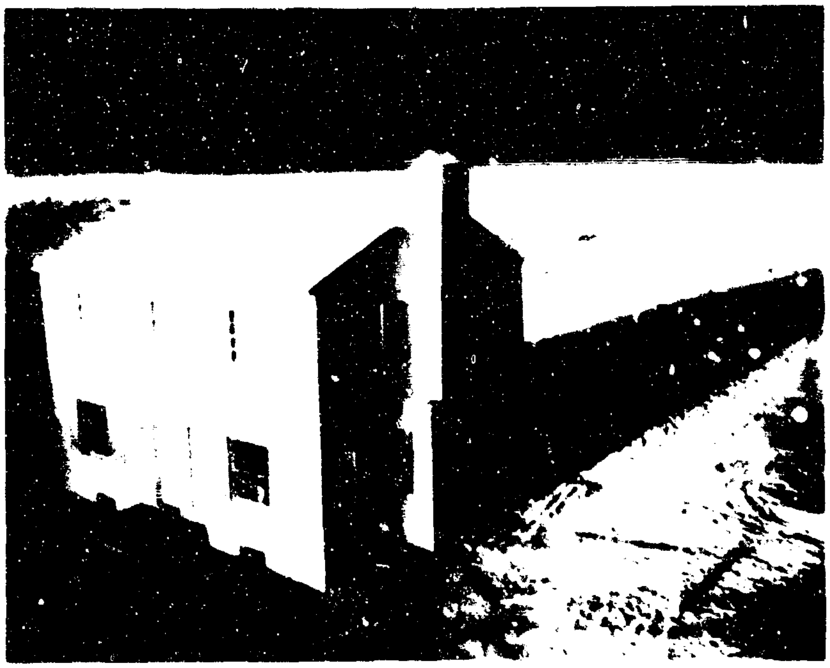

Fig. 1.1—House at 3500 ft, zero time, instant of detonation. The blinding light from the detonation throws the house, the desert, and the surrounding hills into sharp relief.

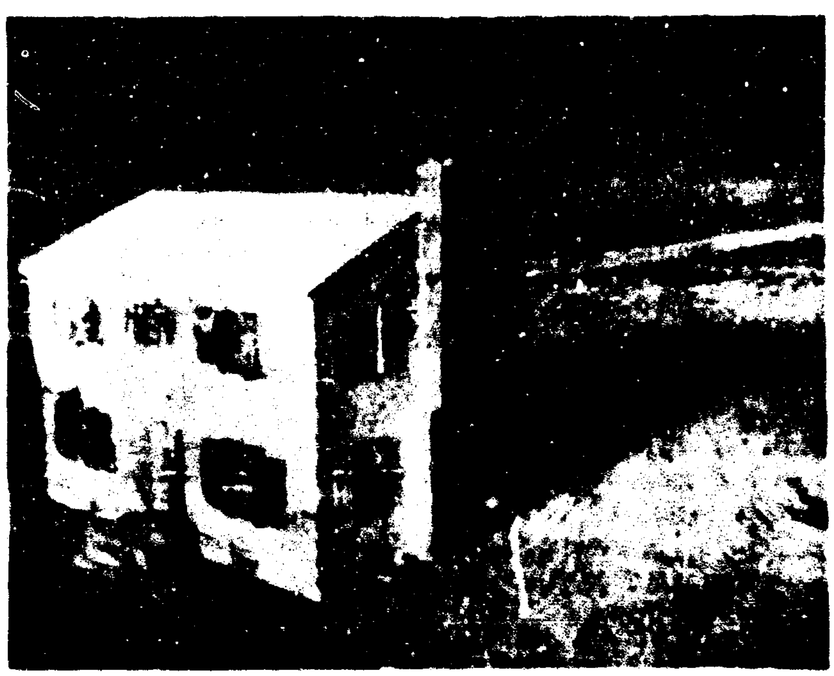

Fig. 1.2—House at 3500 ft, $^{5}/_{24}$ sec after detonation. The charring deepens around the windows and doors; the wood base of the floodlight pole (lower right) is smoking.

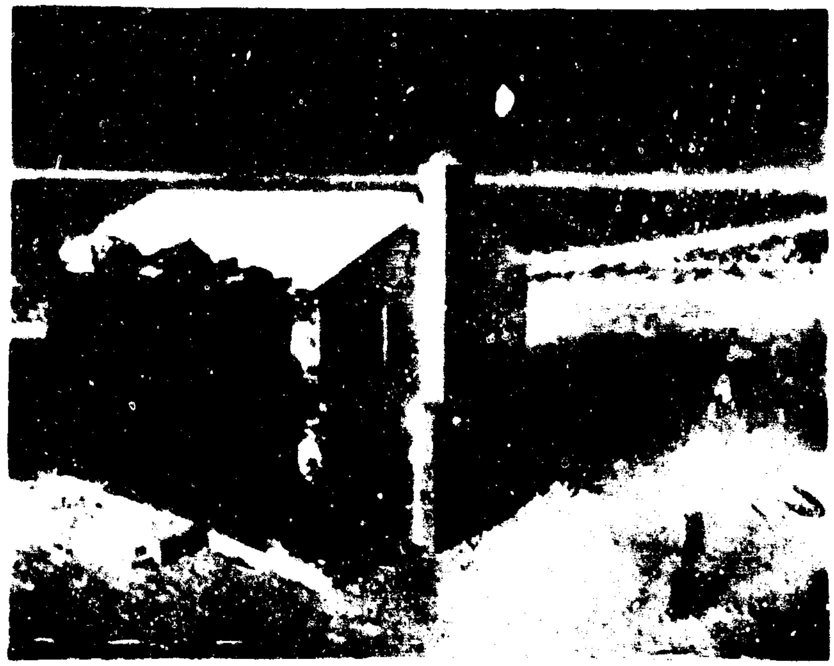

Fig. 1.3—House at 3500 ft, $^{15}/_{64}$ sec after detonation. The front of the house is almost obscured by smoke.

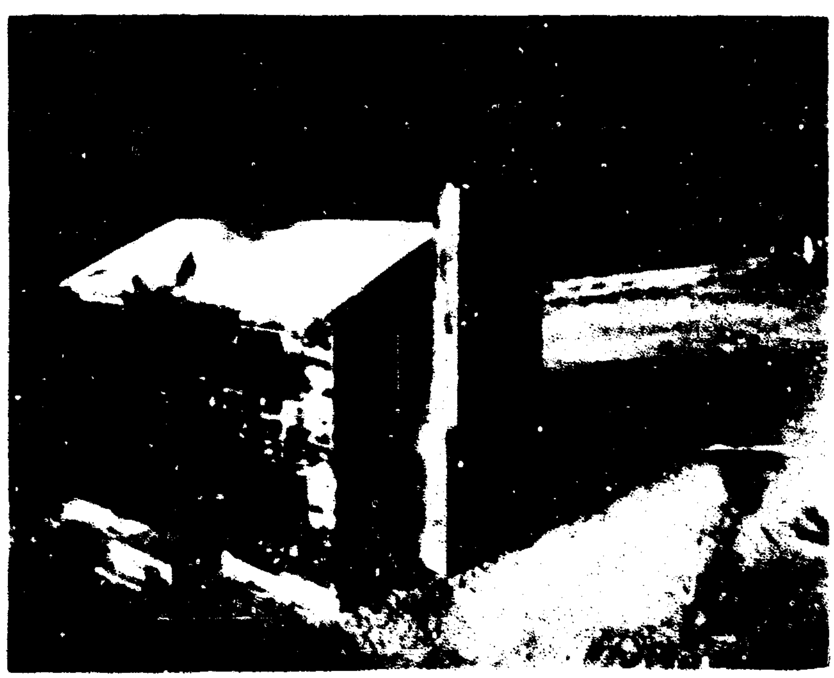

Fig. 1.4—House at 3500 ft, $1^{15}/_{64}$ sec after detonation. The smoke is virtually gone.

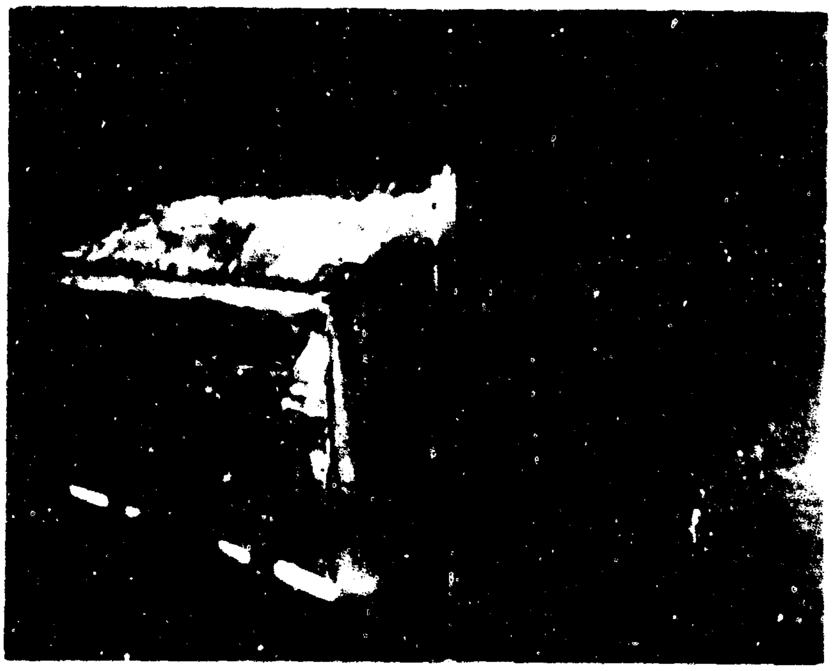

Fig. 1.5—House at 3500 ft, $1\frac{1}{4}$ sec after detonation. The blast arrives. The front buckles, fragments fly from the roof, and the roof itself is ripped upward.

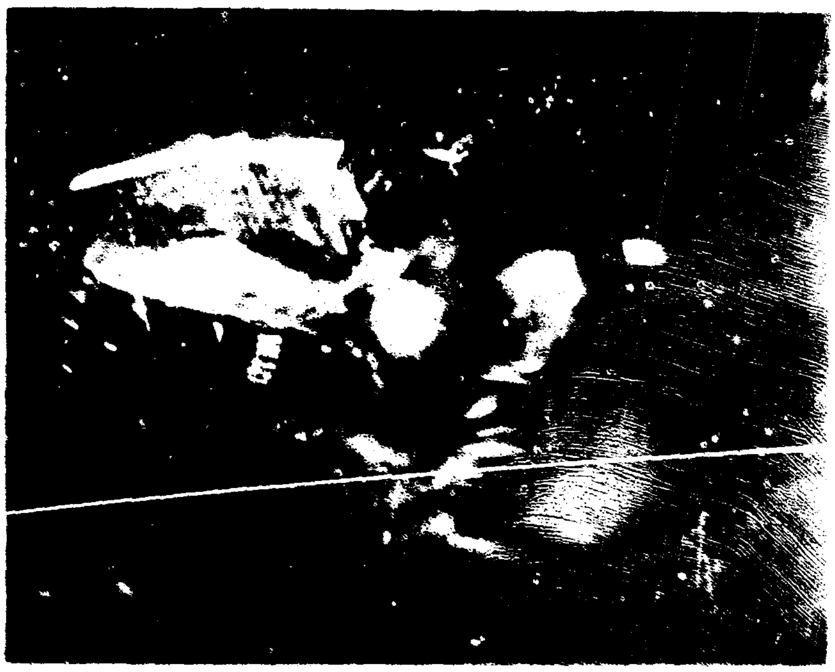

Fig. 1.6—House at 3500 ft, 1[illegible] sec after detonation. The lower front wall is completely destroyed.

Fig. 1.7—House at 3500 ft, $2\frac{3}{24}$ sec after detonation. The second story is being pushed back.

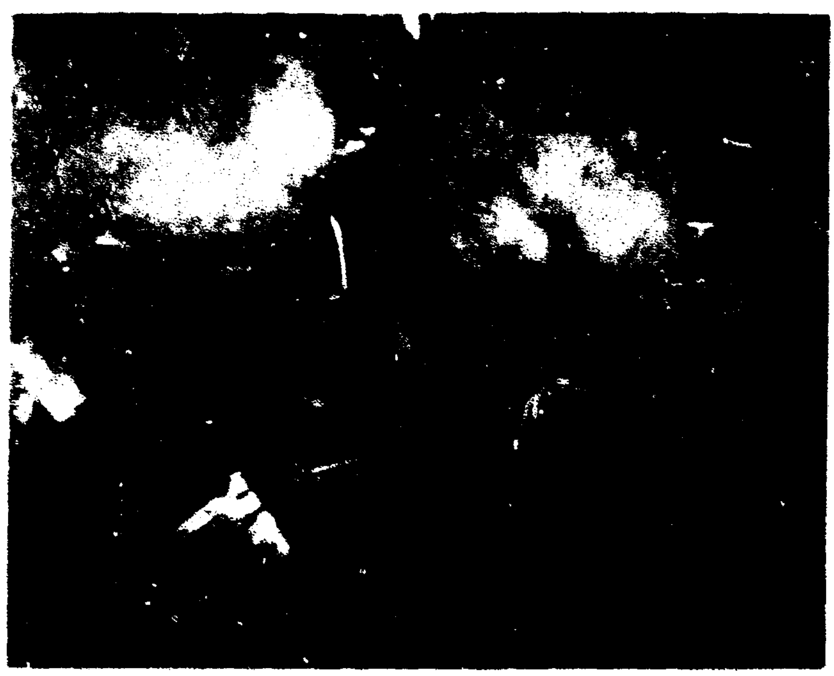

Fig. 1.8—House at 3500 ft, $2\frac{2}{3}$ sec after detonation. This once was a house.

tape slings. Interior badges were taped to wire hangers suspended from first-floor joists. In addition to the badges in the basement, the house at 7500 ft contained one horizontal layer of badges 4 ft 6 in. above the first floor, another layer at the second floor level, another layer 4 ft 6 in. above the second floor, seven badges in the attic on top of the second-floor ceiling, and fifteen badges on the ground at the basement wall outside the house. Locations and total doses recorded by badges are shown in Fig. B.1.

Treated paper temperature-recording strips, mounted on 4- by 5- by $\frac{3}{16}$-in. plywood and furnished by the Quartermaster Research and Development Laboratory of Philadelphia, Pa., were attached to the siding that faced the blast at the front door of the house at 7500 ft and to the pole supporting the floodlights in front of this house (see Fig. B.2). These calibrated strips, white to gray in color, turn black when the temperature for which they are designed is reached.

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2. Department of Defense and Atomic Energy Commission, "Damage from Atomic Explosion and Design of Protective Structures," U. S. Government Printing Office, Washington, 1950.
3. U. S. Strategic Bombing Survey, "The Effect of the Atomic Bomb on Hiroshima, Japan," Vols. I, II, and III, U. S. Government Printing Office, Washington, 1947.
4. U. S. Strategic Bombing Survey, "The Effect of the Atomic Bomb on Nagasaki, Japan," Vols. I, II, and III, U. S. Government Printing Office, Washington, 1947.

CHAPTER 2

TEST RESULTS

2.1 GAMMA-RADIATION SCATTER

At 5:20 a.m. on Mar. 17, 1953, the 16.4-kt bomb was detonated atop a 300-ft tower. Early reports by monitors indicated a heavy radioactive fall-out along a radial line from Ground Zero through the houses. When a structural-safety team, whose duty it was to examine the houses and advise whether they were safe for the observers to inspect, arrived at the house at the 7500-ft range at approximately 7:00 a.m., the monitor's instrument recorded 20 r/hr (roentgens per hour) on the ground at the house, 7 r/hr in the basement, 10 r/hr on the first floor, and 20 r/hr on the second floor. Post-operation plans called for the entry of a damage-evaluation team and a recovery party at 7:30 a.m. to assess the damage and collect the film badges. Because of the high radiation levels, post-operation plans were changed, and only the damage-evaluation team entered at about 12:30 p.m. Most film badges from the 7500-ft house were collected at that time. At noon, March 18 and 19, more badges were taken from the far house. Badges in the house at 3500 ft were recovered on March 18. Because of the collapse of this house, only about 50 per cent of the badges was recovered. Total gamma dosages are shown in Fig. B.1.

2.2 THERMAL-RADIATION EFFECTS

All exterior woodwork of the house at the 3500-ft range was given two coats of whitewash. With the exception of the shutters, which were given a coat of light-gray paint, all exterior woodwork of the house at 7500 ft was given one coat of white undercoating primer. The roof of the house at 3500 ft was covered with square cement-asbestos shingles, while the far-range house had 210# light-gray asphalt roof shingles. Aluminum-finish steel Venetian blinds with noninflammable tapes were installed on the windows facing the blast (front) in both houses. All Venetian blinds were lowered and closed before the shot.

The shutters on the front of the house facing Ground Zero at 7500 ft were scorched, but other exterior woodwork showed no effects of the thermal radiation. No thermal effects were noted inside. The asphalt shingles of this house were not affected by the heat. The temperature-recording strips on the front of the house and on the light pole at 7500 ft indicated a maximum temperature of 249°C or 480°F, although the accuracy of these strips is questionable, especially on account of the short time duration of the thermal radiation and the variation in reflectiveness of the strips.

All exterior woodwork on the front of the house facing Ground Zero at 3500 ft was charred by the thermal radiation. An examination of the motion pictures, frame by frame, showed the front of this house obscured by black smoke but no flame about 0.75 sec after the explosion. At about 1.6 sec, before the blast arrived, the black smoke had generally disappeared, leaving a charred surface. There was no evidence that the interior of the house was affected by the

thermal radiation. The cement-asbestos shingles of this house were broken but showed no evidence of discoloration.

2.3 BLAST EFFECTS

2.3.1 House at 7500 Ft (See Figs. B.3 and B.4)

Figures 2.1 and 2.2 show the far-range house before and after the blast. Figures 2.3 to 2.6 show blast damage from the outside on sides and rear of the house. Doors, windows, and window frames in general either were blasted out of the walls or remained in place in badly damaged condition. The glass in the windows was shattered into small particles and scattered uniformly about the interior of the house. The exceptions to the general rule were four windows in the rear of the house, which had been sheltered by partitions from the blast that entered through the front and side openings, and the basement windows in the rear of the house, which were blown open inward.

The basement was relatively free of debris except for that from the outside entrance doorway and suffered minor damage as shown in Figs. 2.7 and 2.8. The 6- by 8-in. wood girders, pipe columns, and most of the 2- by 8-in. floor joists of the first-floor system were undamaged. Figure 2.9 shows a split joist at about the third point under the kitchen. Figure 2.10 shows, under the dining room, the fourth joist from the front broken at a 4-in. knot, the fifth joist split, and the sixth broken at a 3-in. knot. Figures 2.11 and 2.12 show two views of the floor-joist damage under the living room. The joists framing into the double header were designed to be supported by steel joist hangers but were only spiked to the headers. These nails bent, allowing the supported joists to drop about 3 in. at the support, splitting one joist and pulling out the nails that secured the subflooring to the joists. The trimmers were shown on the architectural drawings as being doubled, but in the construction they were single joists and failed in horizontal shear in one and in bending in the other. Figure 2.11 also shows two other floor joists under the living room which failed in bending at approximately midspan.

Figure 2.13 is a view of the dining room before the explosion; the front facing the blast is to the left in the figure. Figures 2.14 to 2.18 show the damage to and the positions of department-store mannequins in the dining room after the blast.

Figure 2.19 shows the damage in the entrance hall on the first floor.

Figure 2.20 shows the living room before the blast; Fig. 2.21 shows a similar view of the living room after the blast. The child mannequin was found undamaged under the fireplace screen after the explosion but was removed before this photograph was taken. Figure 2.22 shows the rear end of the living room with the Venetian blind from the front window having been blown by the blast about 20 ft from its original position. Extensive damage to plaster and one broken first-story stud are shown in Fig. 2.23, which is a view of the front entrance taken from the living room. Plaster cracks around the fireplace indicated that there had been some deflection inward of the first-story studs in this side of the house.

The kitchen in the rear of the house was protected somewhat by the partition wall between it and the dining room, yet furniture was thrown about, and the door to the dining room was broken and portions embedded in the plaster of the rear wall, as shown in Fig. 2.24. Figure 2.25 shows part of the kitchen-ceiling damage. The kitchen wall on the side of the house, between the door and window, bulged inward slightly, causing plaster cracks, as indicated in Fig. 2.26. The studs in this part of the wall may have been broken.

Figure 2.27 shows the door to the first-floor coat closet ripped off its hinges, turned 180°, and wedged in this position. It also shows the opening to the basement stairs minus the door.

Figure 2.28 shows damage to first-floor lavatory ceiling, apparently caused by upward escape of pressure.

Figure 2.29 indicates what happened to the Venetian blind on the front window and the linen-closet door in the second-floor hall. The door was wedged in place by the bowing, and one slat of the blind was pinched between the top of the door and frame.

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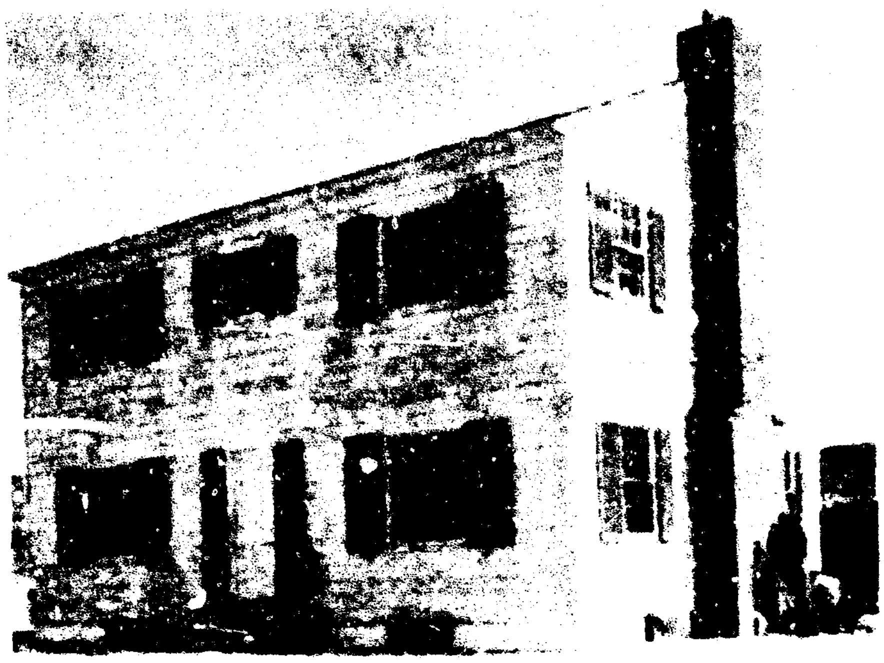


Fig. 2.1—House at 7500 ft before the blast.

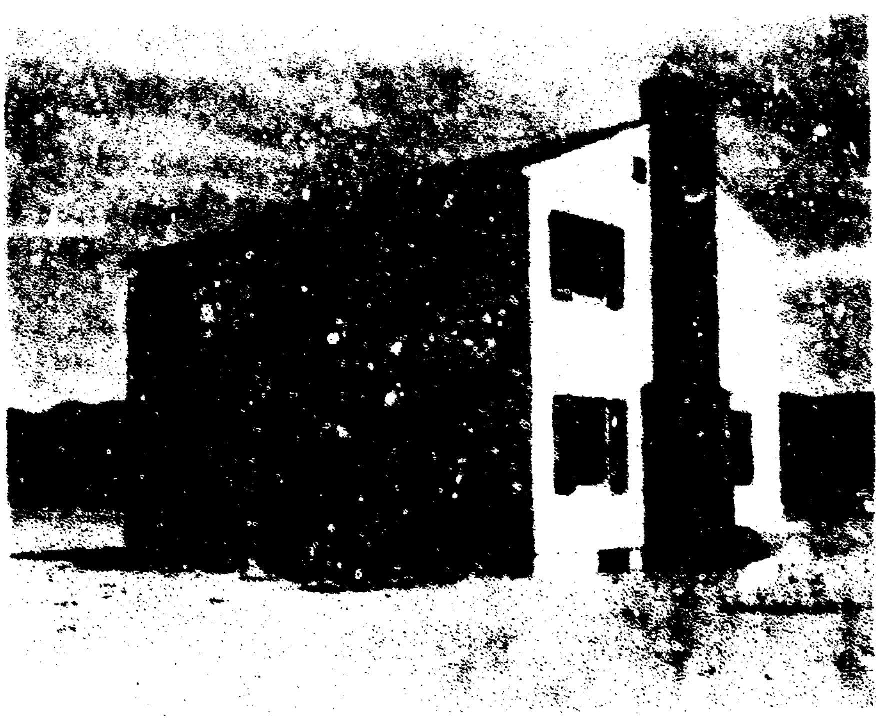


Fig. 2.2—House at 7500 ft after the blast.

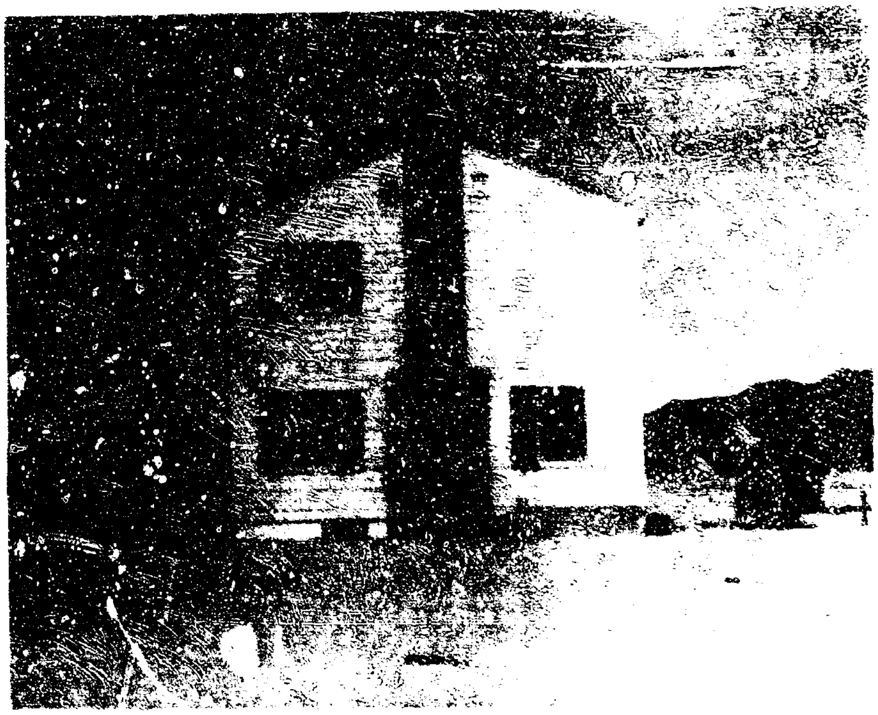


Fig. 2.3—House at 7500 ft after the blast.

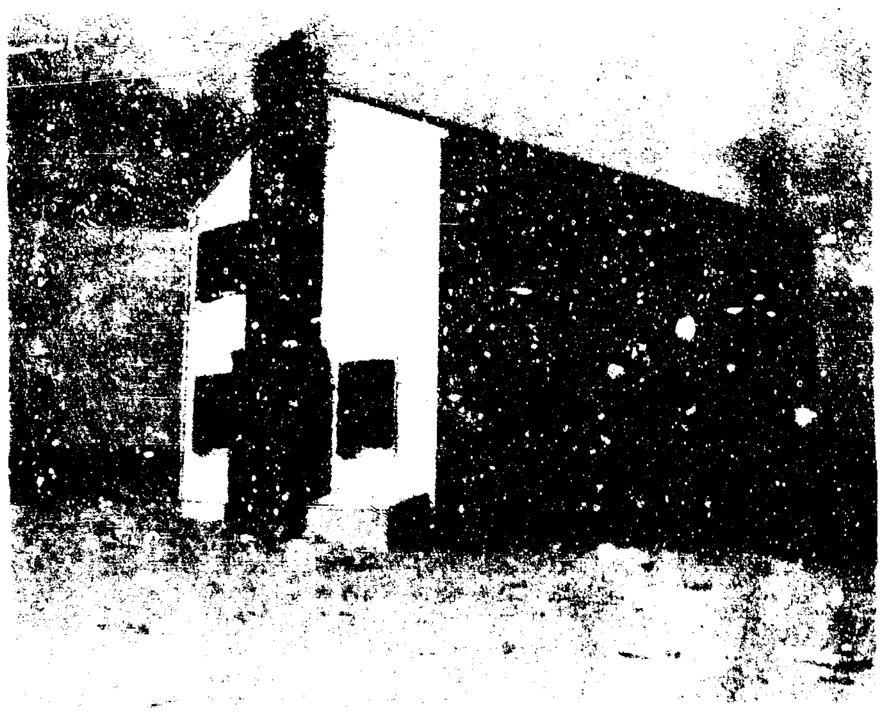


Fig. 2.4—House at 7500 ft after the blast.

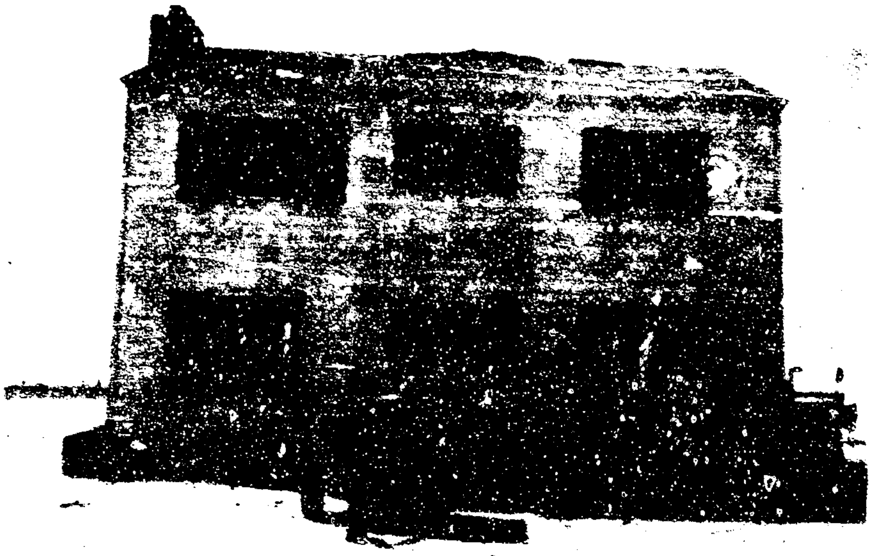


Fig. 2.5—House at 7500 ft after the blast.

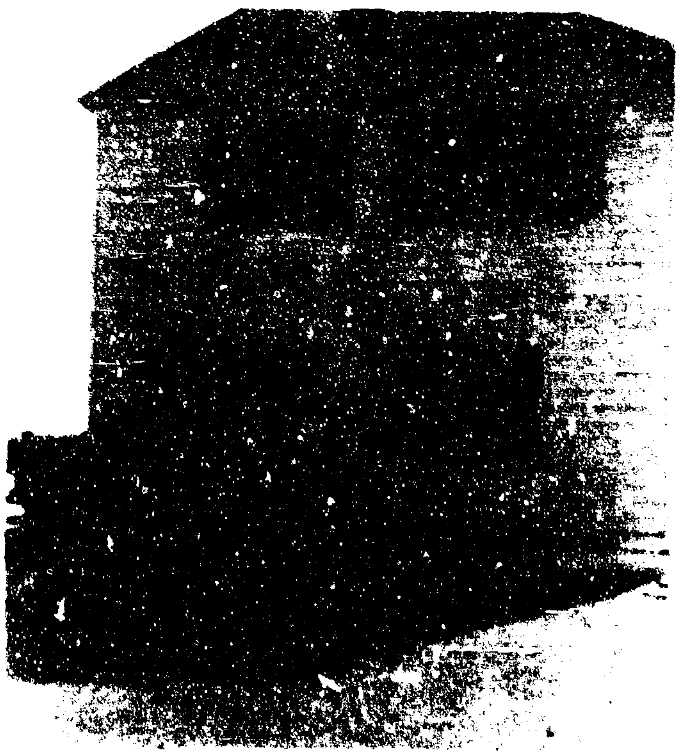


Fig. 2.6—House at 7500 ft after the blast.

Fig. 2.7—Basement of the house at 7500 ft.

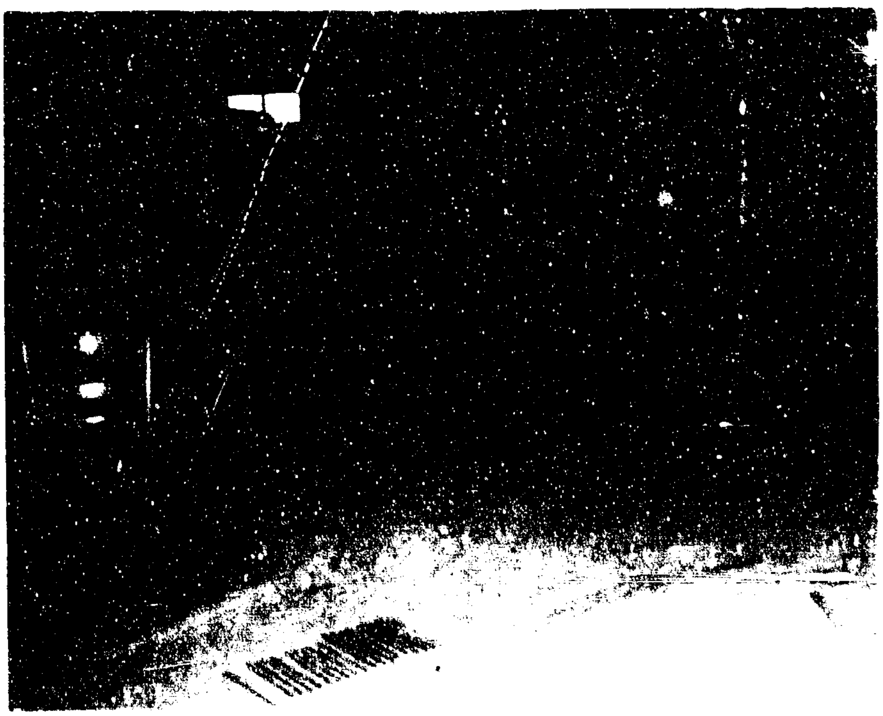


Fig. 2.8—Basement of the house at 7500 ft.

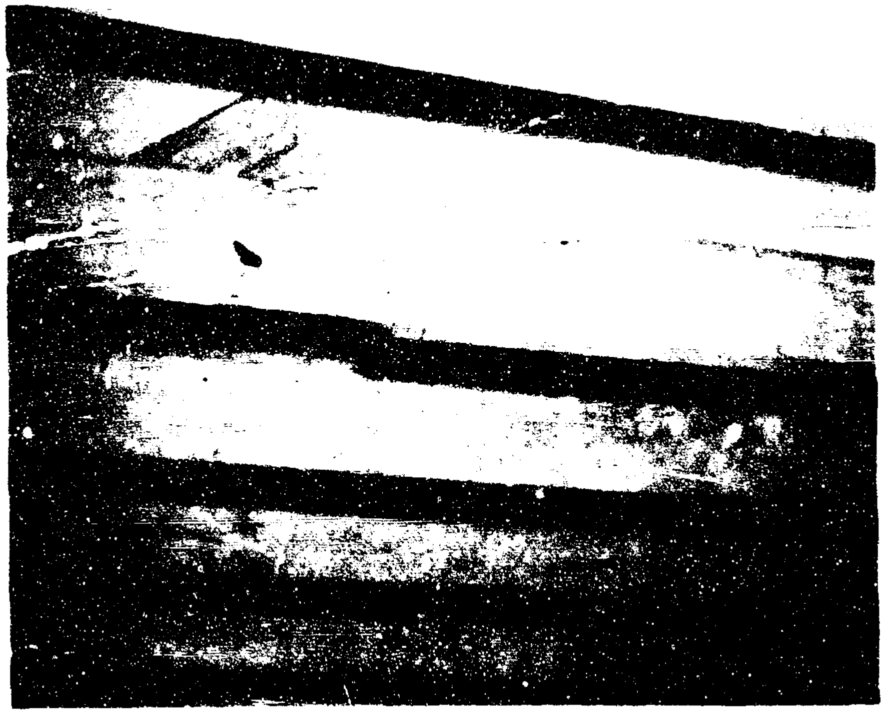


Fig. 2.9—Floor joists under the kitchen.

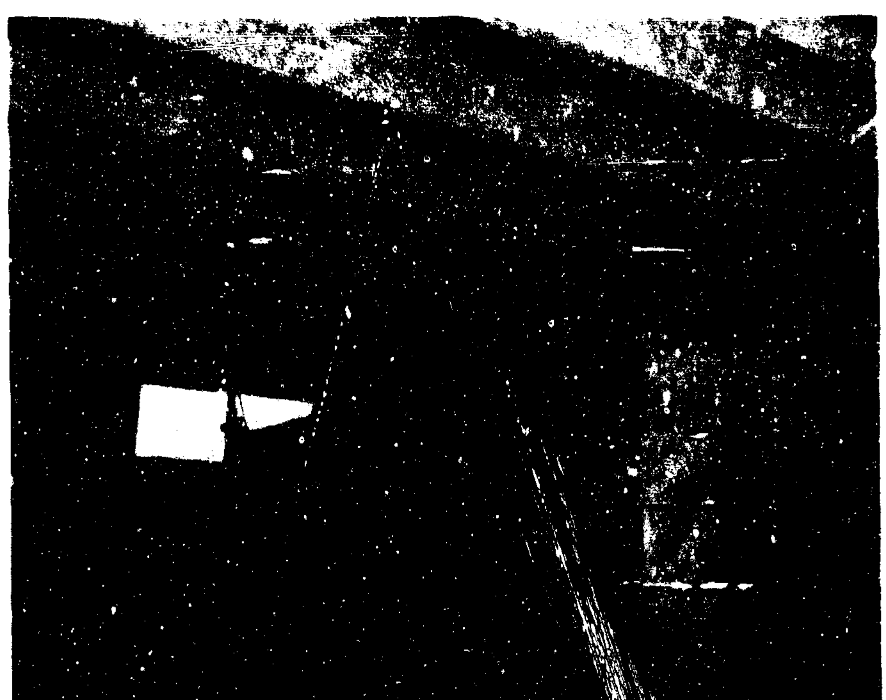


Fig. 2.10—Floor joists under the dining room.

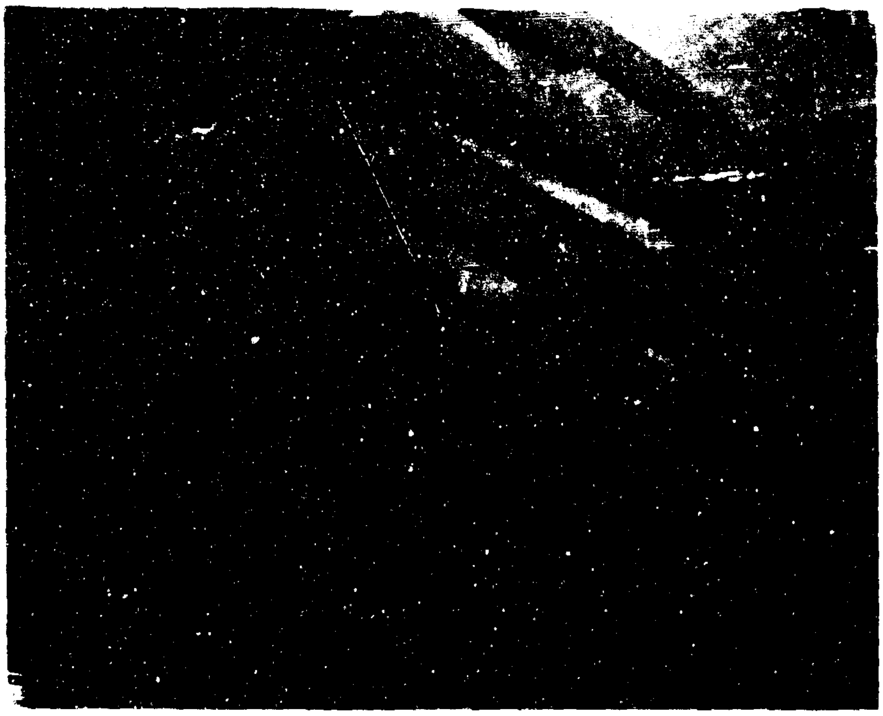


Fig. 2.11—Front floor joists under the living room.

Fig. 2.12—Rear floor joists under the living room.

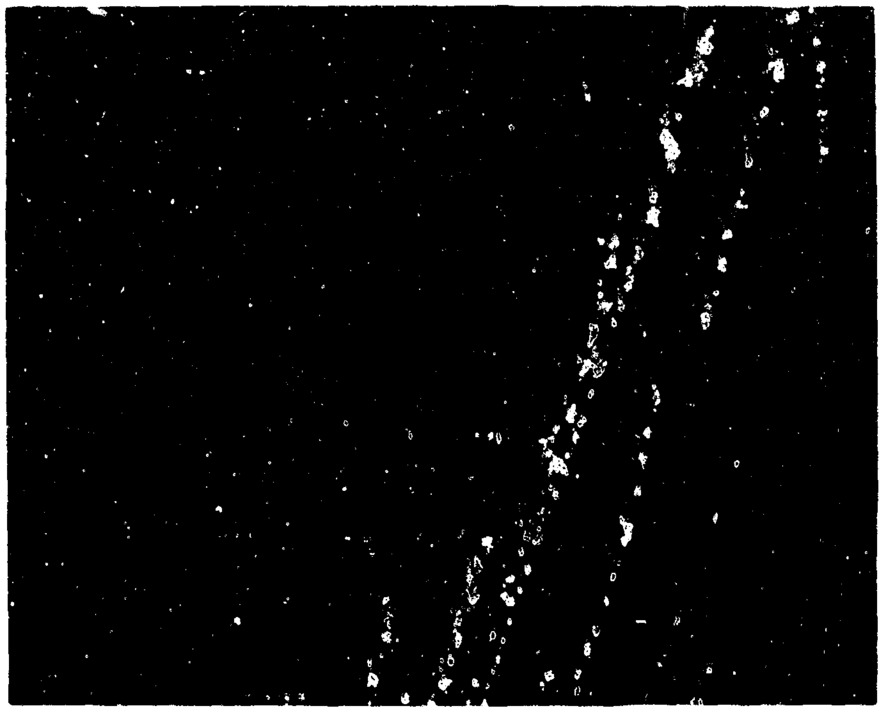


Fig. 2.13—Dining room before the blast.

Fig. 2.14—Dining room after the blast.

Fig. 2.15—Dining room after the blast.

Fig. 2.16—Dining room after the blast, looking toward the front of the house.

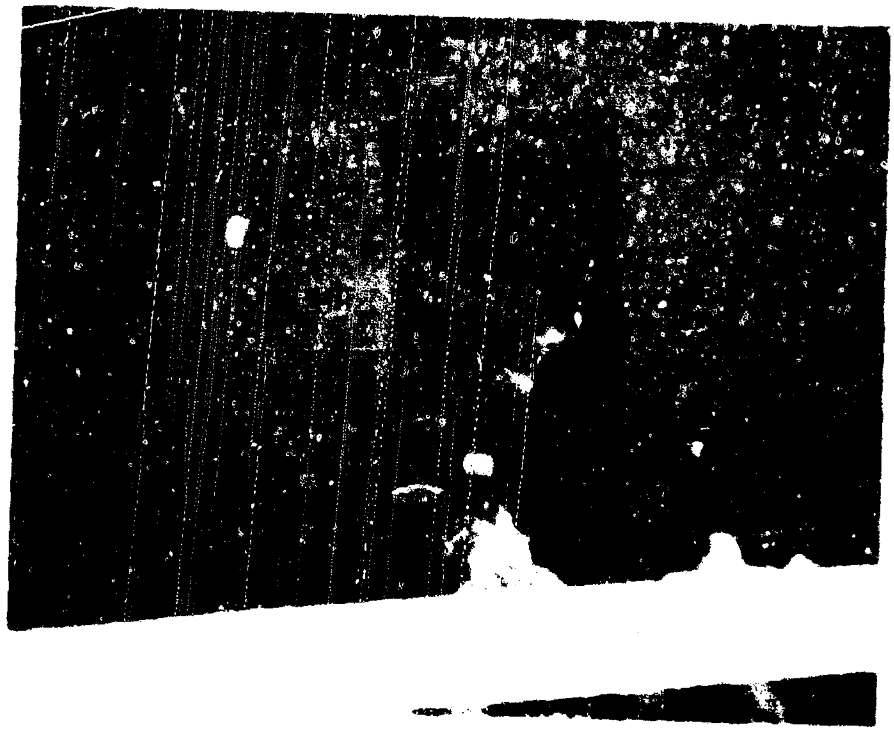


Fig. 2.17—Dining room after the blast.

Fig. 2.18—Dining room after the blast.

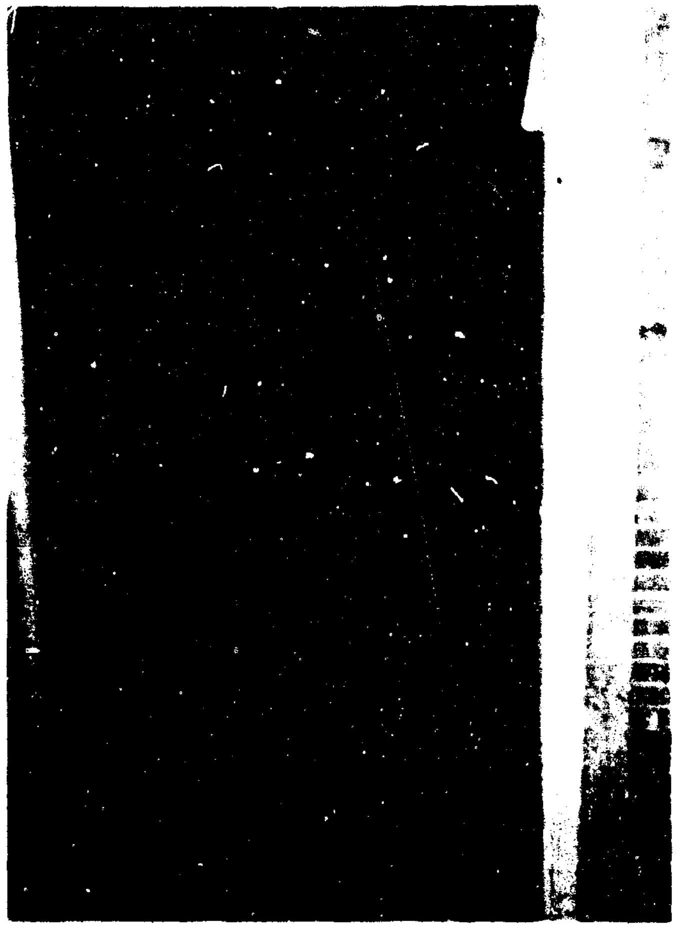


Fig. 2.19—Entrance hall and stairs after the blast.

Fig. 2.20—Living room before the blast.

Fig. 2.21—Living room after the blast.

Fig. 2.22—Rear end of the living room after the blast.

Fig. 2.23—Living room, near the front entrance.

Fig. 2.24—Rear of the kitchen after the blast.

Fig. 2.25—Kitchen wall and ceiling after the blast.

Fig. 2.26—Kitchen entrance after the blast showing plaster cracks.

Fig. 2.27—Coat closet after the blast.

Fig. 2.28—First-floor lavatory ceiling after the blast.

Fig. 2.29—Damage to the second-floor hall at front.

Fig. 2.30—Front bedroom after the blast, looking toward the side.

Figure 2.30 shows the front bedroom. To the left is shown one broken second-story stud, but from the horizontal plaster crack it is probable that the other studs split also. Plaster damage to the back wall of the front bedroom is shown in Fig. 2.31. The door to this room was open at the time of the explosion.

Figure 2.32 is a view of the master bedroom after the blast, looking toward Ground Zero. Deflection and splitting of the second-story studs in the front wall caused considerable plaster damage in this room. Damage to the ceiling may have been caused by unequal pressures in the attic and second story or by the weakening of the plaster due to the blast, with later removal by wind. The mannequin on the bed was not moved, but the covering was stripped from the bed.

Figure 2.33 is a view of the front roof rafters taken through the hole in the master-bedroom ceiling. Only one broken roof rafter is visible However, all roof rafters on the front of the house with the exception of one near the gable end were broken at approximately midspan (see Fig. 2.34). A photograph (Fig. 2.35) taken through a hole in the rear-bedroom ceiling shows the ridge board, which was carried down by the broken rafters in the front of the house, and the rear roof rafters that suffered no damage. Figure 2.36 shows damage to the south closet in the master bedroom and the Venetian blind from the front window of this room.

The house leaned toward the rear, the eave at the back overhanging the rear basement wall an estimated 1 or 2 in.

2.3.2 House at 3500 Ft (See Figs. B.3 and B.4)

Figure 2.37 shows the front (facing the blast) of the near-range house before the explosion. Figure 2.38 shows a general view of the house after the blast, taken from about the same point. Moving around the house from the front counterclockwise, the damage is shown on the other three faces in Figs. 2.39 to 2.41. In the foreground of Fig. 2.41 the floor of the kitchen entrance is shown in an upside-down position. The house was demolished beyond repair.

Figure 2.42 shows the large area over which debris was scattered. The front half of the roof broke in the middle at approximately the midspan of the rafters, the lower part lifting at the eaves, as shown by motion pictures, pivoting about the break, and sailing through the air to land on the ground in the rear of the house (see Fig. 2.43). The upper part of this broken roof was found upside down on the ground in front of the house, as shown in Fig. 2.44. The rear half of the roof slid off the house to the rear over a test automobile shown in Fig. 2.45. This section was later laid on the ground at the back of the house and can be seen in Fig. 2.43.

The chimney fell toward the rear of the house at an angle of about 45° to a line to Ground Zero and was found lying on the ground broken into large sections. Because of the clouds of dust raised during the final collapse of the house, it is difficult to determine from the motion pictures whether the breakup of the chimney occurred before or after it reached the ground.

The first-story stud walls were disintegrated by the blast and allowed the second story to drop on the first floor. Most of the living-room floor sagged into the basement due to broken joists. The first-floor framing system moved, in general, as a unit toward the rear of the house, about 2 ft at the right side (looking at the front of the house) and 1 ft at the left (see Fig. 2.46 which shows the distance that the first floor moved at the basement corner-room shelter). The ends of the 6- by 8-in. wood girders were pushed through the masonry foundation wall at the rear of the house, as shown in Figs. 2.47 and 2.48. The ends of the wood girders at the front of the house moved off their bearings (Fig. 2.49) a maximum distance of 1 ft 3 in., and the girders cantilevered from the front pair of pipe columns. Base and cap plates of the pipe columns leaned to the rear but did not overturn.

The kitchen-floor joists and those under the dining room, which were not supported by the basement corner-room shelter, broke and projected into the basement (see Figs. 2.50 and 2.51).

The kitchen and dining-room areas were completely covered with debris and with the second floor. Mannequins in the dining room were buried under the wreckage.

Figure 2.52 shows the living room with the store mannequins buried in the debris. This part of the first floor sagged into the basement space, as shown in Fig. 2.53, which is a view of the underside of the living-room floor from the rear part of the basement.

(Text continues on page 49.)

Fig. 2.31—Front-bedroom plaster damage.

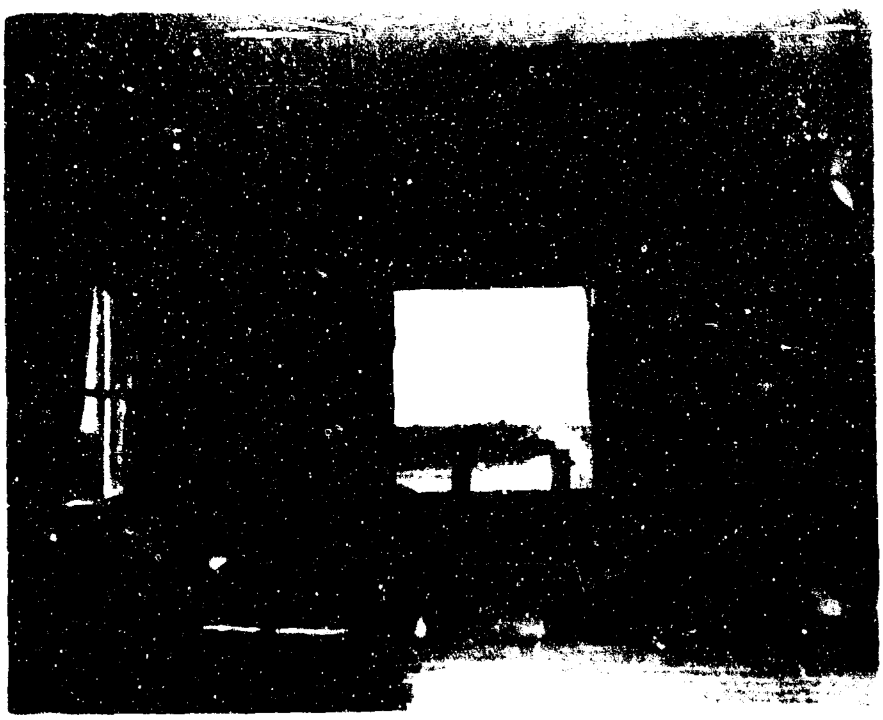


Fig. 2.32—Master-bedroom damage, looking toward the front.

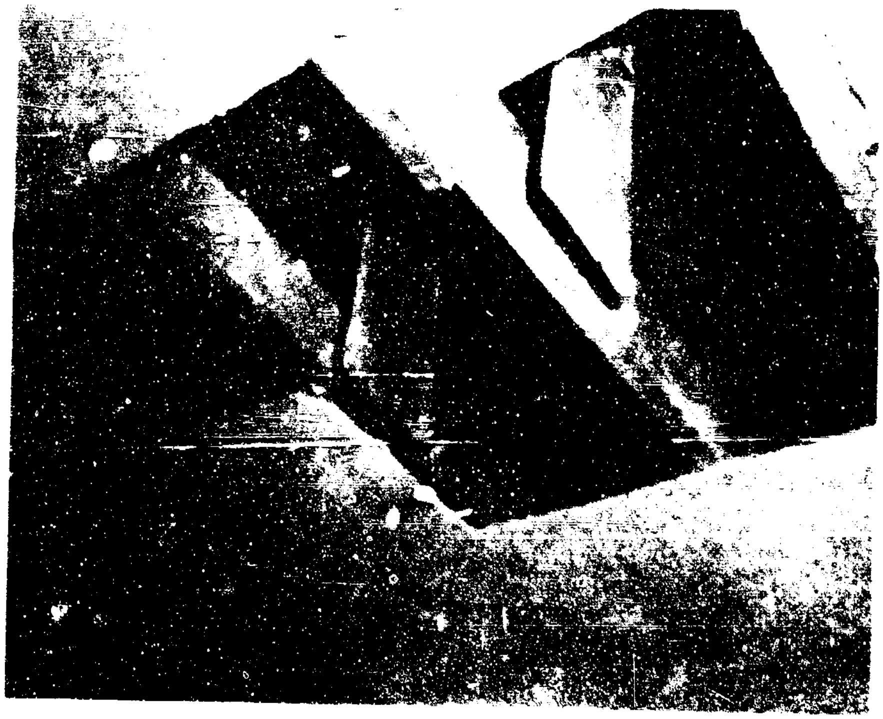


Fig. 2.33—Master-bedroom ceiling damage.

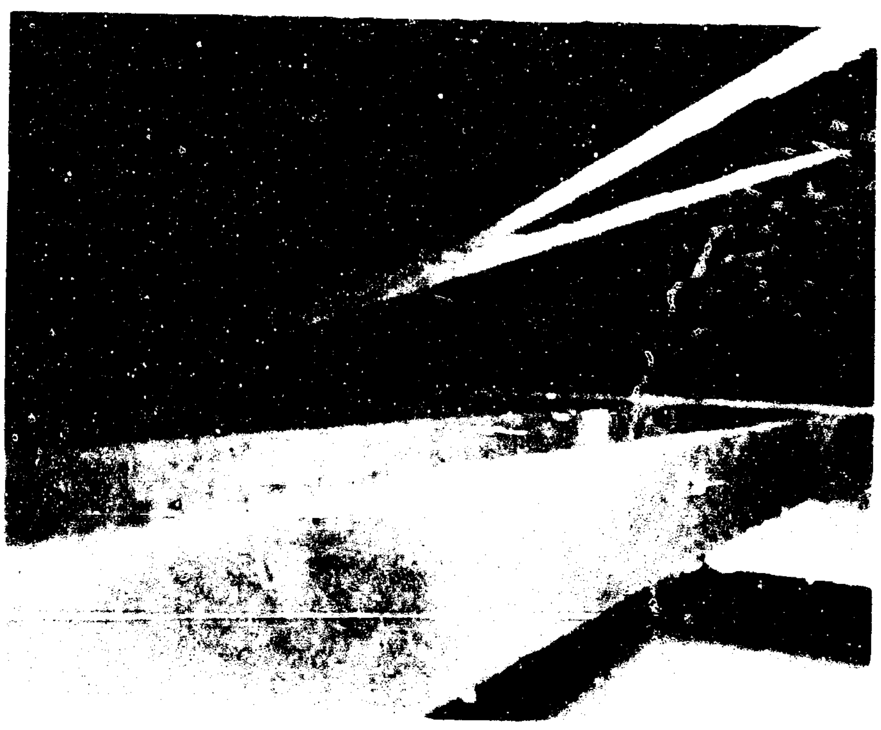


Fig. 2.34—Damage to the roof, front of house at 7500 ft.

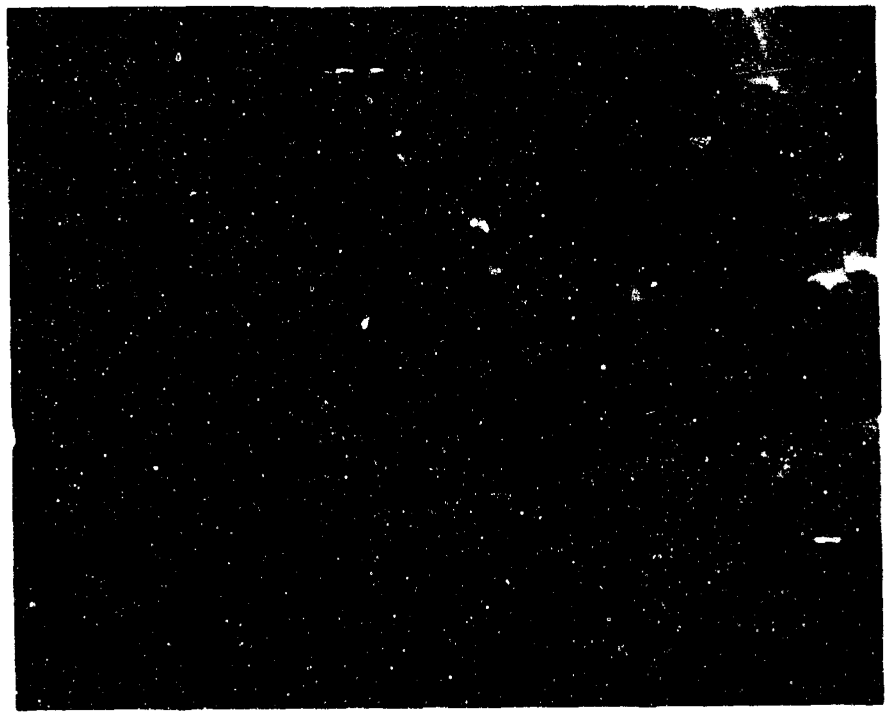


Fig. 2.35—Ridge and roof rafters at the rear of the house.

Fig. 2.36—Master-bedroom closet.

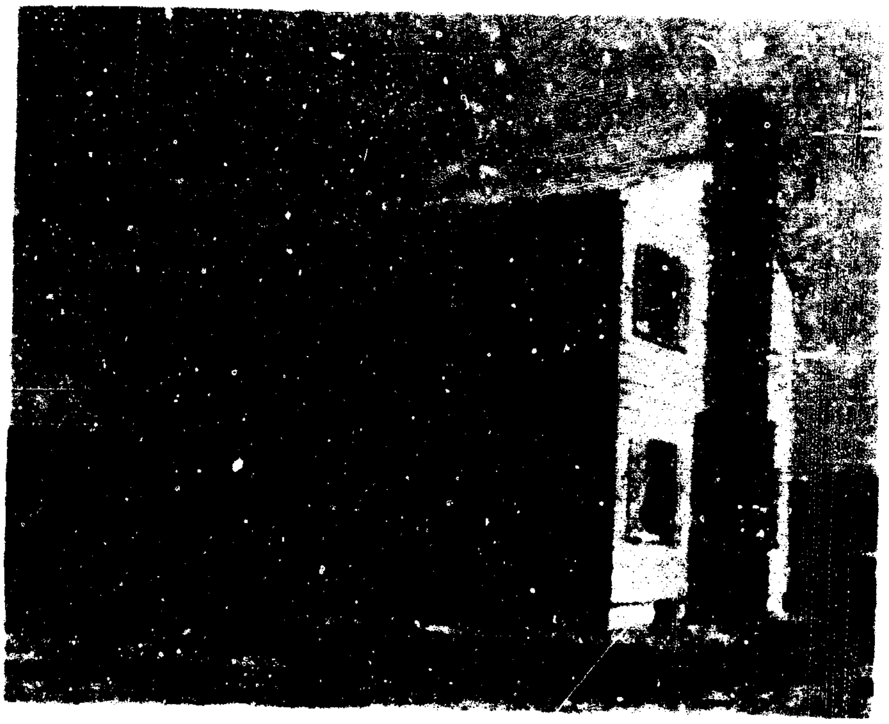


Fig. 2.37—House at 3500 ft before the blast.

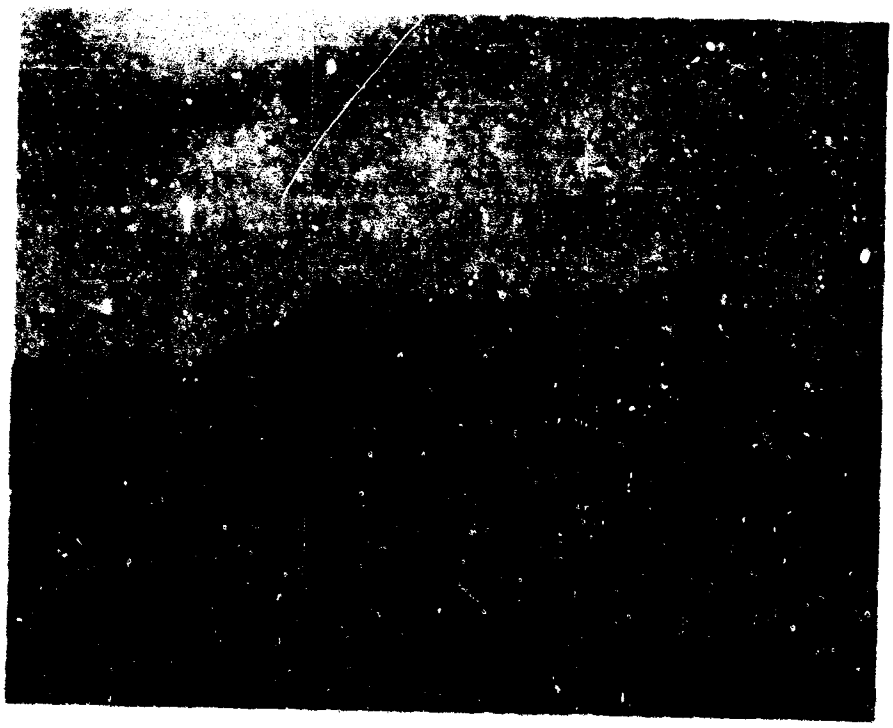


Fig. 2.38—House at 3500 ft after the blast.

Fig. 2.39—Side of the house at 3500 ft.

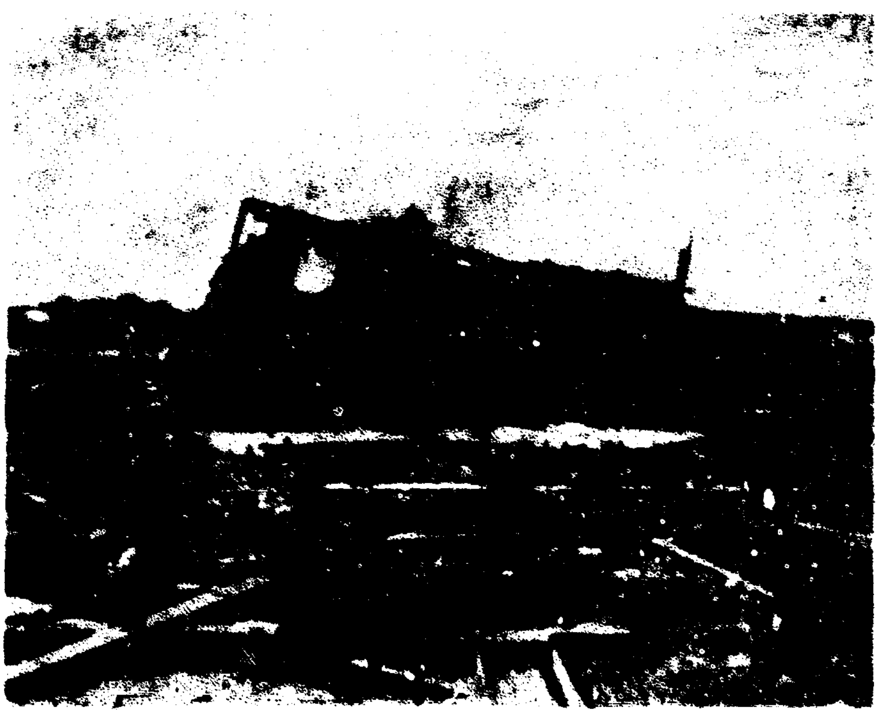


Fig. 2.40—Rear of the house at 3500 ft.

Fig. 2.41—Kitchen side of the house at 3500 ft.

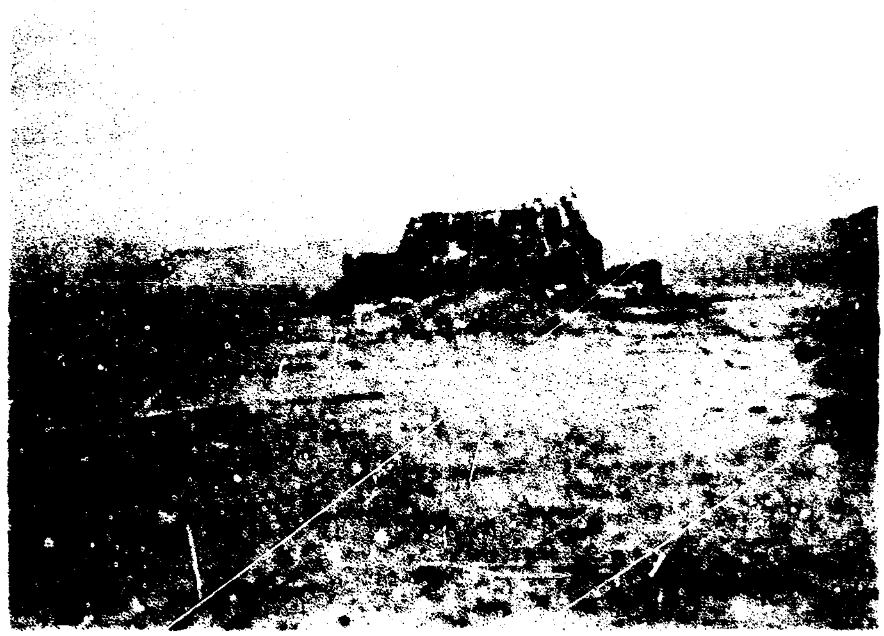


Fig. 2.42—Debris from the house at 3500 ft.

Fig. 2.43—Lower portion of the front section of the roof.

Fig. 2.44—Upper portion of the front section of the roof.

Fig. 2.45—Rear section of the roof.

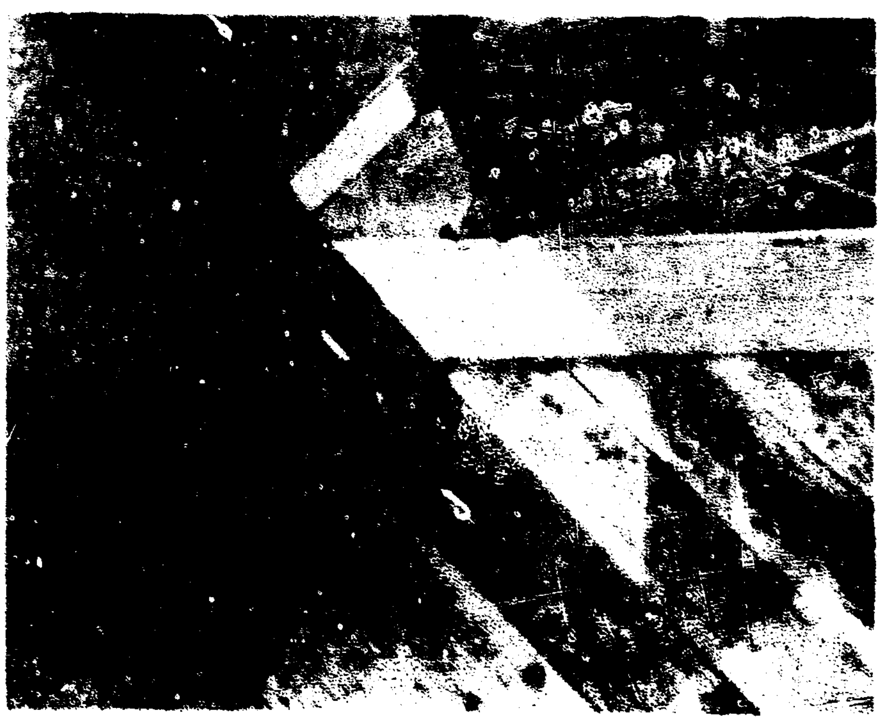


Fig. 2.46—Displacement of the first floor over the corner-room shelter.

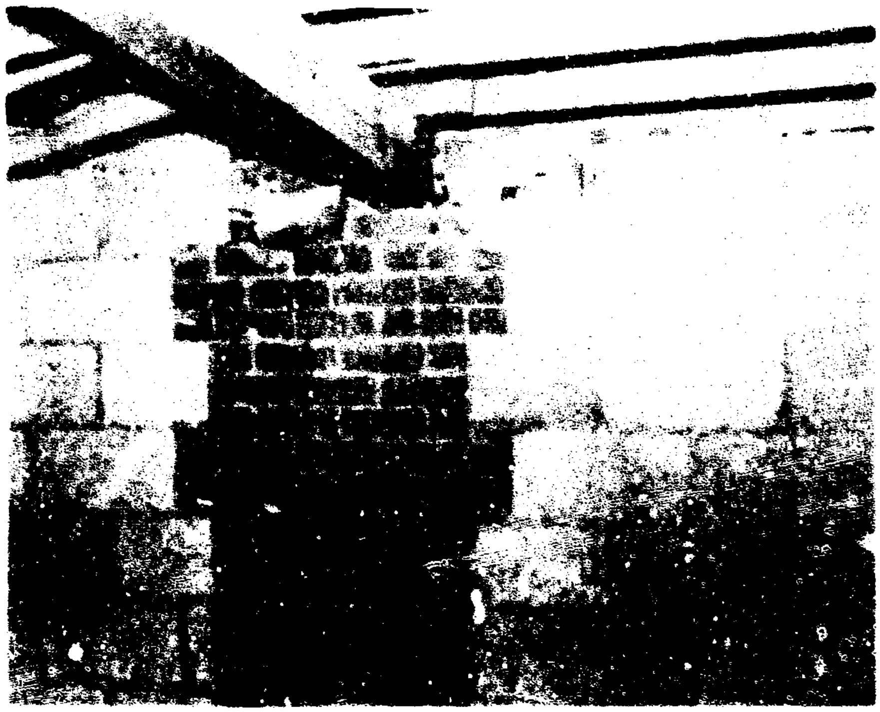


Fig. 2.47—Rear wall punctured by a wood girder.

Fig. 2.48—Basement, showing damage to the living-room floor.

Fig. 2.49—Front ends of the wood girders.

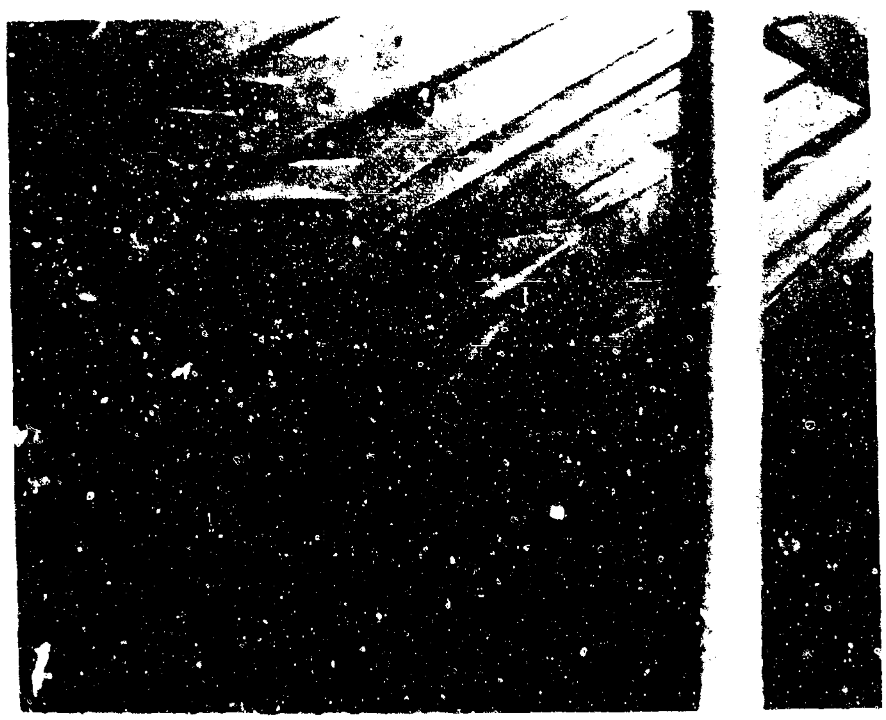


Fig. 2.50—Damage to the kitchen and dining-room floors, toward the basement door.

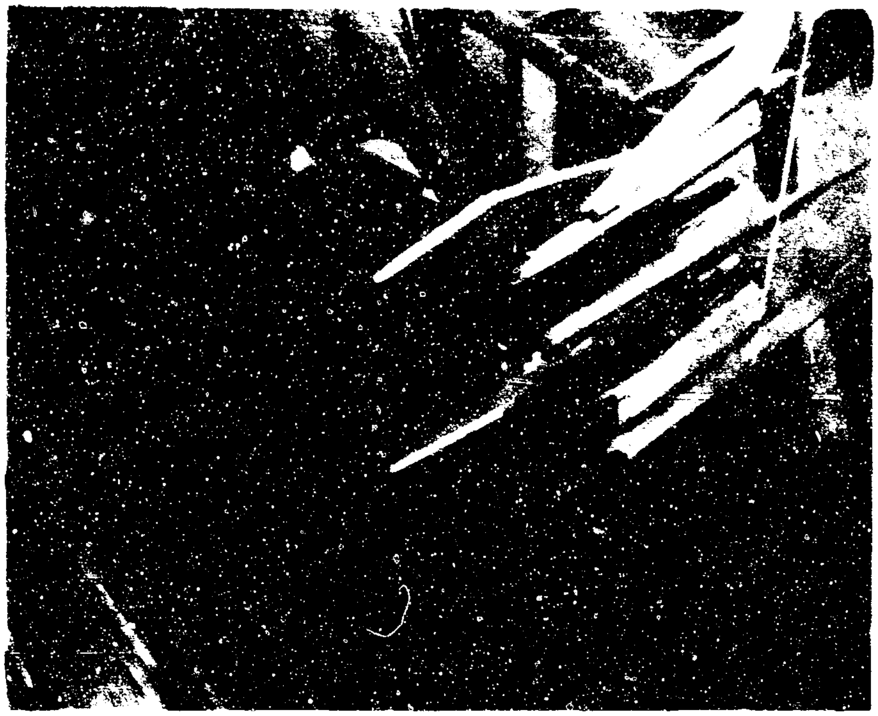


Fig. 2.51—Damage to the kitchen and dining-room floors.

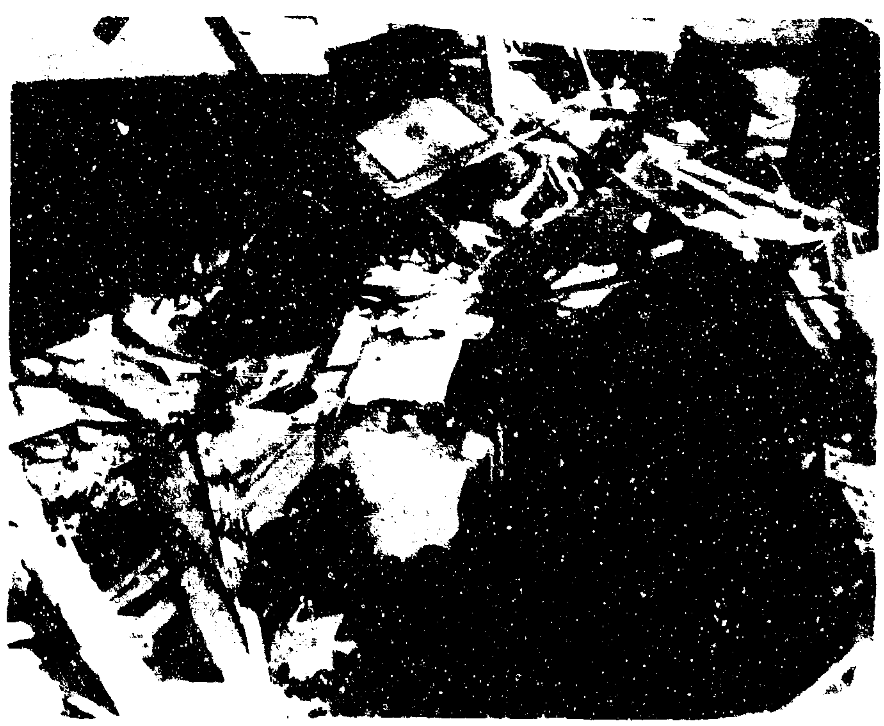


Fig. 2.52—Living room from the front of the house.

Fig. 2.53—Underside of the living-room floor.

Fig. 2.54—Basement stairs, showing position of upper flight.

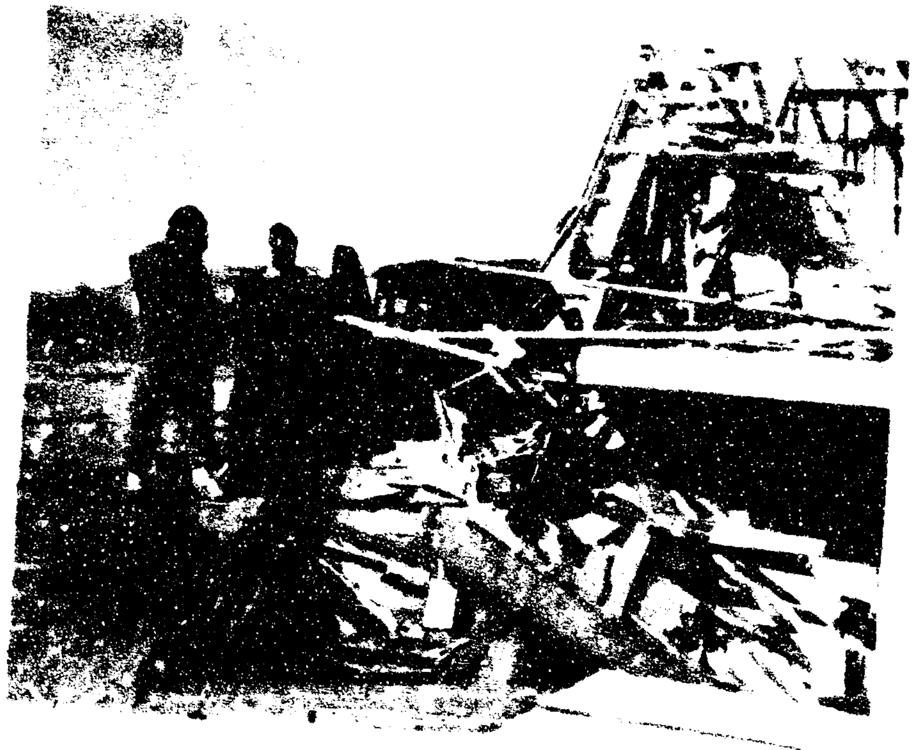


Fig. 2.55—Rotation and movement of the second story at front.

Fig. 2.56—Damage to the second-floor rear bedroom.

Fig. 2.57—Front foundation wall above grade after the blast.

Figure 2.54 shows how the stairs from the first to the second floor collapsed into the basement stairwell when the second story dropped on the first floor.

The second story did not drop vertically on the first floor but moved with a clockwise rotation in relation to the front basement wall of the house. The right front corner of the second floor settled 5 ft 8 in. from the front and 8 ft 3 in. from the right-side basement wall, while the left front corner of the second floor was 12 ft from the front basement wall and overhung the left-side basement wall by 10 ft 2 in. The motion appeared to be a rotation and a movement toward the left rear corner of the foundation wall. This is shown in Fig. 2.55.

Figure 2.56 shows a distinguishable second-floor rear bedroom which fell on top of the kitchen.

The box-sill construction used at the top of the block foundation wall failed. Generally, the 2- by 8-in. plate, which was bolted to the block wall, remained in place. In the front of the house, the 2- by 8-in. closure or header split at the top horizontally, with the top portion moving with the first floor and the lower portion remaining with the plate, as shown in Fig. 2.55. At the sides of the house, where the closure was nailed into the ends of the floor joists, the nails bent, allowing the joists to slide to the rear of the house with the floor and separating the closure from the plate. This is also illustrated in Fig. 2.55.

The foundation wall above grade suffered little damage on the front and sides but was damaged at the rear by the movement of the first-floor system. However, the front foundation wall (Fig. 2.57) was cracked through vertically from sill to basement floor at each end, about 1 ft from the corner, and was moved in at the top about 1 in., hinging at the basement floor level. The hinged wall showed no bowing or cracking, however. Lateral earth pressure due to the pressure on the ground in front of the house was the most probable cause of this effect.

CHAPTER 3

DISCUSSION

3.1 ANALYSIS OF GAMMA-RADIATION DATA

Badges were placed in both houses to measure initial gamma radiation. Recovery of the badges was expected within 2 hr after detonation. A severe fall-out delayed post operation plans. Some of the badges from the house at 7500 ft were recovered 7 hr after the blast. The other badges were picked up 24 and 48 hr later. Badges in the house at 3500 ft were collected 31 hr after the explosion.

High residual-radiation levels, based on allowable tolerances, remained in the area for two days. Monitor reports showed wide fluctuations in readings, probably due to the shifting of the sand and dust under the action of the wind. Under these conditions it was impossible to differentiate between the amounts of initial and residual radiation to which the badges had been exposed. This part of the test failed because of unforeseen conditions. Only a small sector of the test area encompassing the dwelling sites was contaminated by fall-out due to wind direction.

3.2 ANALYSIS OF THERMAL-RADIATION-EFFECTS DATA

3.2.1 House at 7500 Ft

A single coat of white paint seemed to provide a satisfactory reflective surface which prevented scorching of the siding. The one coat of light-gray paint on the shutters, however, absorbed enough thermal radiation to scorch the exposed surfaces of the shutters.

The thermal-recording strips were designed to indicate thermal flux in terms of calories per square centimeter. Although Fig. B.2 shows the temperature at which the individual strips turn black, these values are significant only under conditions comparable to those of calibration. Calibration in terms of bomb flux exposure was performed during shots 9 and 10, with the following results:

Thermal flux, cal/cm^2	Strip blackened
24	All
13	All
11	All
7.8-7.9	Up to 249°C
6.0	Up to 199-249°C
4.6	Up to 199-214°C
3.7	Up to 175-199°C
2.5	Up to 138-175°C

It is seen that the calibration is not sharp, but that different boards react slightly differently.

During use on the houses, therefore, blackening of a particular strip does not necessarily mean that the surface attained the corresponding temperature, but that it was subject to the corresponding flux. Since the slight difference in color between the siding and shutters on this house introduced some difference in heat absorption on the surfaces, it seems likely that the temperatures attained by the surfaces and by the thermal strips all differed markedly from one another.

No scorching was evident inside the house, and no primary fire resulted from the detonation. Since the house contained no utilities, it is not known whether their presence would have caused a secondary fire.

3.2.2 House at 3500 Ft

The side of this house facing the detonation was charred from the thermal radiation. The motion pictures showed that the charring and smoke were first evident in the area of the soft wood of the shutters and the front-door sill, where the whitewash was worn off by traffic or sand. No flame was visible at any time. Black smoke was caused by the rapid combustion of the wood under the heat. There was no evidence in the collapsed interior to indicate any scorching or fire damage.

No primary fire resulted from the detonation. This house, like the far-range one, contained no utilities. The collapsing house would have caused damage to utilities, but the probability of a secondary fire under such conditions cannot be predicted.

3.3 ANALYSIS OF BLAST-EFFECTS DATA

3.3.1 House at 7500 Ft

Doors and windows in the front and sides of this house failed. The window glass broke into small fragments. This breaking force was transferred to the muntins, which broke away from the sash. The frames of the double-hung windows were fastened in the stud wall openings only by the nails through the trim on the inside of the house. The force exerted on the sash pushed the frames in the front of the house into the rooms. Since the pressure on the sides of the house was less the frames in these walls were only partially dislodged from the walls.

Considerably less damage to the sash would have occurred if, instead of the commercial type of sash with its comparatively weak muntins, a stronger improved design had been specified. The window frames would probably have remained in place in the walls if they had been nailed through blocks into the studs of the jambs.

The destruction of the front entrance door was complete, while the kitchen and basement entrance doors, which were torn off their hinges, suffered much less damage. These latter doors contained glass which constituted about 20 per cent of their area. When the glass broke, the pressure on these doors was relieved and probably prevented their destruction. This is uncertain, however, since the blast pressure on the side of the house theoretically should have been less than on the front.

Damage to interior doors varied. The front-bedroom door, which was left open, suffered no damage since it offered no resistance to the transmission of pressure. The door between the kitchen and dining room was the most severely damaged of all since it was normal to the pressure build-up in the dining room and provided the most direct and least resistant exit to the rear for the blast. Because the windows in the first story were larger than those in the basement, the pressure build-up must have been greater in the first story than in the basement, and this pressure, seeking relief in a lower-pressure area, broke the door to the basement and, as described later, probably the floor joists. The coat-closet door was driven off its hinges and rotated 180° in the closet. One panel broke and probably allowed the pressure of the small volume of air in the closet to equalize quickly, thus preventing complete destruction of the door. The closet doors in the second story acted similarly to those on the first floor, with one

exception — the linen-closet door. This door bowed in but did not break. The pressure on this door was probably not as great because of the effect on the pressure wave of the partition corner in front of it.

In the front of the house the 2- by 6-in. roof rafters, which were spaced 16 in. on centers, failed in bending at the middle of the span. While the size of these rafters is satisfactory for the usual static load, this test proved that, under blast loading, the roof construction was the weakest structural part of this house. No other structural portions failed so completely.

The second-floor framing apparently was undamaged. This was expected, since the window areas in both first and second stories were nearly the same, and rapid equalization of pressure both above and below the floor could occur. Equalization of pressure above and below the first floor must have been slower since several of the first-floor joists failed or partially failed as a result of a downward load. Pressure entering the basement had to channel through windows totaling only about 30 per cent of the first-story window area, with a resulting slower build-up. Twelve of the first-floor joists were damaged because of overloading, and most of these contained large knots at or near the bottom edges. These joists possessed much less strength than the other joists because of these knots. Under the living room, part of the joist damage was due to faulty construction. The joists framing into the header at the fireplace, instead of being supported by steel joist hangers, were end-nailed. Pressure on the first floor forced the ends of these joists down from the header. A redistribution of the load to the adjoining joists that had solid bearings probably took place. If the trimmer joists had been doubled, as indicated on the drawings, the probability of failure of these joists would have been reduced and a lesser loading would have been imposed on adjacent joists.

Two 2- by 4-in. broken studs are shown in the front wall of the house, where the plasterboard and plaster were removed by the blast or wind. No attempt was made to determine the total damage to studs by removing plaster as working time in the area was limited by the residual-radiation levels. Plaster cracking and bulging inward of walls indicated that other studs in the living room, kitchen, and bedrooms were damaged. In the kitchen, half the load breaking the door and window was transferred to the studs in the 2-ft wall panel between the window and the door, in addition to its own loading. Additional studs placed in this panel may have prevented this damage.

The calculated reflected pressure on the front of the house was 4 psi. The actual reflected pressure must have been less than this value, due to the relief afforded by the breaking of the window glass and the rarefaction effect on the relatively narrow front of the structure. This may explain the small amount of damage done to the studs in the front wall of the house.

3.3.2 House at 3500 Ft

The collapse of the first-story stud walls allowed what remained of the upper part of the house to drop to the first-floor level. The second-story stud walls, except those at the rear of the house where the pressure should be the least, were also demolished. The roof was removed by the blast, and the second-story partitions, although badly damaged, helped to prevent a complete "pancake" collapse. The motion pictures showed a noticeable deflection inward of the front walls between the first and second floors and also between the second floor and roof when the blast struck. This indicated that the studs at the front of the house failed in bending and possibly in horizontal shear. The studs in the other walls probably failed in the same manner, although the mode is uncertain. The destruction of the walls was so complete that it would have been difficult to determine the exact cause of failure.

The estimated reflected pressure on the front of the house was 12 psi. The actual reflected pressure is unknown, but it probably was less than 12 psi because of the effect of windows and shape.

The entire house moved off its foundation because the sill construction, shown in Fig. B.3, did not have sufficient strength to transfer the shear to the basement wall. If the transfer had occurred, the block wall might have failed and the first-story studs might have split at the ends because of horizontal shear.

In order to resist pressures at this range, the framing of this house would have to be redesigned. Conventional methods of wood house construction would have to be considerably modified. Walls would have to be made stronger, and joints between walls, floors, and roof would have to be more rigid. Interior partitions should be made to act as shear walls and be securely anchored to floors and ceilings. The roof would require strengthening and would have to be firmly attached to the exterior walls to prevent separation. To resist the lateral force tending to move the house off its foundations, special attention should be given to the anchorage of the house to the masonry basement walls and also the wall itself. Any basement columns should be braced against lateral movement. The first-floor framing should be designed for the blast load that enters the first story through broken windows and doors.

3.4 CONCLUSIONS

Observation of the mannequins in the house at 7500 ft after the blast indicated that human beings on the first and second floors would have been injured by flying glass or debris. In the basement of the same house they would have been relatively safe. The crushed and broken mannequins in the house at 3500 ft showed that people would have been either seriously injured or killed on the first and second floors. In the basement, without shelter, their safety would have been a matter of chance location.

Major damage to multilight double-hung wood sash may be expected at overpressures of 2 psi. Frames may be partially displaced at the same pressure and, at about 4 psi, may be forced out of stud walls. To reduce window damage, consideration should be given to using stronger sash and glass and better anchorage of frames.

There is some evidence that interior wood-panel doors will generally escape destruction if they are left in an open position. Exterior doors and their fastenings would have to be redesigned to withstand a pressure of 4 psi.

On the side facing the blast, rafters of a conventional wood gable roof, which are designed for the usual static load, will fail under overpressures of from 2 to 4 psi and break in half at 5 to 12 psi. Strengthening of the roof could be effected by increasing the size of the rafters, by the use of light wooden roof trusses with subdivided top chords or, where attic space may be used as rooms, wood stud-partition framing at about the third points.

In cases where windows and doors fail and allow the blast to enter, first-floor joists in a typical wood-frame house will be subjected to additional loading due to unequal pressures in the basement and first story. The joists may suffer little damage in a conventional house at the 2-psi range if care is exercised in selecting joists and keeping knots from the tension edges. At larger pressures and under similar conditions of blast, the first-floor joists should be increased in size or spaced more closely. Header joists in floors should be supported by steel joist hangers, and trimmers should be doubled.

Wall studs, 2 by 4 in., spaced 16 in. on center act to transfer the lateral bending loads to the floor systems but may be expected to suffer damage at overpressures of 2 to 4 psi and break at 5 to 12 psi. Stud walls at the lower pressures should be strengthened by closer spacing of the studs. At higher pressures the walls will require special study involving modification of conventional practices.

Extensive damage to plasterboard and plaster will occur in a wood-frame house exposed to an overpressure on the ground of 2 psi. Consideration should be given to the use of less fragile and more elastic material.

A conventional wood-frame house will be severely damaged at an overpressure of 2 psi and will be destroyed at 5 psi.

3.5 RECOMMENDATIONS

No information as to pressures in the interior of the house was obtained in this test. Future test structures should be instrumented with pressure gauges to study interior pressure build-up and should be provided with means of relieving or preventing it.

Estimated reflected pressures on the front faces of the houses were 4 and 12 psi, respectively. Since the window openings and comparatively short dimension of the building have some effect, reflected pressures on the front face and roof should be measured in a field test of houses.

A general knowledge of the type of damage to be expected to an existing typical wood-frame American home when exposed to blast overpressures from 2 to 5 psi was obtained in this test. The next step should be to consider means of building more blast-resistant houses in the future. Since wood is the most used building material in home construction, efforts should be directed toward feasible wood designs for pressures of about 5 psi. Several of these designs should be included in future test programs.

APPENDIX A

SPECIFICATIONS*

I. GENERAL SCOPE

This addendum applies to the dwellings and supplements the basic specification which shall be applicable to these buildings except where inconsistent with this addendum.

The number and location of these buildings are as follows:

No. required	Description	Location from GZ
2	Two-story wood frame (Type H7)	5 and 2 psi (one at each range)

II. OBJECTIVE

It is the intent of this specification to obtain construction of representative American dwellings, complete except as noted. All material and workmanship shall equal or exceed minimum requirements for standard residential construction. Each item of material, equipment, or work shall equal or exceed that described herein or on the drawings. All parts shall be sound, and all construction free of defects. All work shall be performed in a workmanlike manner, in accordance with good practice, and be subject to inspection by the Government. Before final acceptance all buildings shall be complete, all equipment installed and connected in operating condition.

III. MASONRY WORK

Brick for dwellings shall be common brick as covered in the basic specification.

IV. CONCRETE WORK

Concrete for residences shall be Type A as covered in the basic specification.

* FCDA Addendum No. 2 to "Specifications for Home Type Shelter, Public Type Shelter and Test Units," prepared by Ammann & Whitney Consulting Engineers, New York, N. Y., for FCDA under Contract DA49-129-eng-151 with the Office, Chief of Engineers, Department of the Army.

V. SHEET-METAL WORK

(a) Flashing and counterflashing shall be No. 26 gauge galvanized sheet metal.

(b) Where basement window sills are below grade, No. 16 gauge semicircular corrugated hot-dipped galvanized sheet-metal window-wall linings with 3-in. lugs shall be furnished and secured to walls.

VI. WOOD CONSTRUCTION

(a) Lumber

Lumber shall comply with Federal Specifications noted in the basic specification, Section 7, and with American Lumber Standards and shall bear the official grade mark and symbol of the association recognized in the trade as covering the particular species. All grade marking shall be done under the supervision of the manufacturer's association responsible for the grading standards for the species involved, or an inspection bureau recognized and authorized by the manufacturer's association responsible for the grading standards to grade according to such rules. The kinds of lumber and boards to be used in the construction of the buildings are given in the table below. Lumber shall have a moisture content not to exceed 19 per cent at the time dwellings are enclosed.

Description	Two story
Exterior walls	
Sheathing	No. 2 Pine or Fir
Siding	"B" Pine or Fir
Studs, plates, and soles	No. 2 Pine or Fir
Interior walls	
Studs, plates, and soles	No. 2 Pine or Fir
Furring	....
Floors	
Joists	No. 2 Pine or Fir
Subfloor (diagonal)	No. 2 Pine or Fir
Finish floor, T.G., F.G.	"C" Pine or Fir
Bridging	No. 2 Pine or Fir
Girders	No. 2 Pine or Fir
Ceilings and flat roofs	
Joists	No. 2 Pine or Fir
Gable roofs	
Rafters	No. 2 Pine or Fir
Sheathing	No. 2 Pine or Fir
Stairs	
Riser	No. 1 Pine
Treads (bullnosed)	No. 1 Pine

(b) Framing—General

1. Structural Framing Members. Members shall be of sizes scheduled and nailed as described below. Splicing joists between bearing points will not be permitted. When structural strength is impaired by cutting or drilling by other trades or by inherent defects, members shall be replaced or reinforced in a manner acceptable to the Contracting Officer.

2. Framing at Chimney. Bearing of framing members on chimney masonry is not acceptable. Headers and trimmers shall be framed flush with steel joist hangers. Framing member shall not be closer than 2 in. to chimney masonry, and the 2-in. space shall be filled with incombustible material.

3. Firestopping. Outside stud walls and furring space of masonry walls shall be fire-stopped at first floor and attic.

4. Recommended Nailing Schedule. Joints in framing shall be nailed with common nails according to the following schedule:

Joist to sill or girders, toe-nail	3-16d
Bridging to joist, toe-nail each end	2-8d
1- by 6-in. subfloor to joist, face-nail	2-8d
1- by 8-in. subfloor to joist, face-nail	3-8d
Sole plate to joist or blocking	20d 16 in. o.c.
Top plate to stud, end-nail	2-16d
Stud to sole plate, toe-nail	3-16d
Double studs	16d-30 in. o.c.
Top plates, spiked together	16d-24 in. o.c.
Laps and intersections	3-16d
To parallel alternate rafters	3-16d
Rafter to plate	3-16d
1- by 8-in. sheathing or less, to bearing	2-8d
Over 1- by 8-in. sheathing, to bearing	3-8d
Corner studs and angles	3-8d

Other joints, nail to provide proportionate strength

5. Floor Joists. The floor joists shall be of the size and spacing shown on the plans.

6. Framing over Girders and Bearing Partitions. End of joist shall be lapped and spiked together or butted over center of bearing. When butted, tie with metal strap ($\frac{1}{8}$ by 1 by 18 in. minimum).

7. Double Joists. Joists shall be doubled under all bearing partitions and under plaster-finished nonbearing partitions when parallel to floor joist.

8. Headers and Trimmers. Headers receiving more than four tail beams shall be supported by steel joist hangers. Headers 4 ft or less may be single and shall be supported as above or by wood bearing strips or other supports acceptable to the Contracting Officer.

When openings occur at end of joist span and header is 4 ft or less in length, trimmers may be single.

Double framing shall be used under all other conditions.

9. Cross Bridging. Bridging shall be 1 by 3 in. minimum size and shall be spaced 8 ft apart, nailed at each end. Bridging split in process of nailing is not acceptable.

10. Subflooring. Subfloor boards shall be square edge. The boards shall be laid diagonally at 45° angle. Break joints over center of joists; no two adjoining boards shall break joints over the same joist, and each board shall bear on at least three joists. Board shall be double-nailed at each bearing, except 8-in.-wide boards which shall be triple-nailed. Install blocking between ends of joist at wall for nailing ends of floor.

11. Ceiling Framing. Ceiling joists and spacing shall be as shown and noted on the plans.

Use ceiling joists as ties for rafters.

Framing for ceiling joists over girders and bearing partition shall be as specified in paragraph 6 above.

12. Roof Framing. Headers 4 ft or less in length may be single. At the chimney, single trimmers will be permitted.

Wall plates for rafters shall be anchored to masonry walls as indicated on the plans.

On pitched roofs the rafters shall be cut for level bearing and spiked to wall plate; frame rafters opposite one another at ridge.

Collar beams of 2 by 4 in., spaced 48 in. o.c., shall be installed on the rafters where called for on the plans.

(c) Framing Details

1. Studs shall be continuous without splicing between bearings. All studs will be 2 by 4 in., spaced 16 in. o.c. Corner posts shall be three 2- by 4-in. posts, set to receive interior finish. Inner studs at jambs, for window and door openings, shall extend in one piece from header to bearing and shall be nailed to outer studs.

2. Headers over openings shall be not less than the following sizes:

Size	Max. span
Two 2 by 4's on edge	3 ft 6 in.
Two 2 by 6's on edge	4 ft 6 in.
Two 2 by 8's on edge	6 ft 0 in.
Two 2 by 10's on edge	7 ft 6 in.

3. Top plates shall be two 2 by 4's, unless otherwise indicated on the drawings. Plate members shall be lapped at corners and intersecting partitions.

4. Sole plates shall be 2 in. nominal thickness and rest on top of subflooring. The exterior wall studs shall bear on the sole plates.

5. All nonbearing partitions shall have 2- by 4-in. studs, spaced 16 in. o.c. Corner of rooms shall be framed to receive interior finish. The inner stud of jambs shall extend in one piece from header to bearing. Sole and plate shall be 2 in. nominal thickness; lap plates at outside walls and at bearing partition. When partitions are parallel to ceiling joists, a nailing member secured to joists by blocking shall be provided on top of plate for securing ceiling finish.

6. Sheathing. All wall sheathing shall be applied diagonally at 45° angle. Break joints over center of studs; no two joints of adjoining boards shall break joints over same stud, and each board shall bear on at least three studs.

7. Roof Sheathing. The roof sheathing shall break joints over center of rafters; no two adjoining boards shall break joints over same rafter, and each board shall bear on at least three rafters.

8. Stairs (Interior). Stringers, treads, and risers shall be No. 1 pine. Provide solid bearing at top and bottom. The method of stair assembly shall be acceptable to the Contracting Officer. Three 2-by-12 stringers shall be used.

(d) Exterior Wood Siding

1. All exterior wood siding shall be seasoned, with a moisture content not exceeding 19 per cent, and nailed over approved 15# asphalt-impregnated felt, nailed to the sheathing. Nail siding at each bearing as per nailing schedule, set nails, and seal with putty after priming.

2. Exterior Wood Trim. Exterior wood trim and cornice shall be No. 1 fir. Set nails and seal with putty after prime coat of paint has been applied.

3. Shutters and louvers shall be provided as shown. Shutters shall be hinged to window jambs and provided with catches and "S" straps.

(e) Roof Covering

1. Provide cement-asbestos square roof shingles for house near range and light-gray asphalt roof shingles square thick butt 210# for house far range.

2. Fire Underwriters' Class C label shall appear on each bundle of asphalt shingles. The asphalt shingles shall be installed in accordance with manufacturer's specifications, laid over 15# felt, and conform to Federal Specification SS-R-521.

3. Asbestos shingles shall be of an approved quality and shall be applied as recommended by the manufacturer, laid over 15# felt, and conform to Federal Specification SS-S-291b.

4. Flashing. Galvanized sheet metal of No. 26 gauge shall be used for flashing where called for on the plans. All chimney and roof intersections shall be flashed and counterflashed.

(f) Interior Finish

1. For interior finish of exterior walls: Dwellings shall have $^3/_8$-in. gypsum lath, nailed direct to wood stud walls, and have one coat of brown gypsum plaster $^3/_8$ in. thick.

2. For both faces of interior walls and ceilings: Gypsum lath and plaster shall be used. All plaster base shall conform to Federal Specification SS-P-431a for gypsum plasterboard.

3. Plaster shall be gypsum plaster conforming to Federal Specification SS-P-402 and applied in one coat totaling $^3/_8$ in. in thickness.

Install the baseboards of the sizes shown on plans before the application of the plaster, metal corner beads at external corners, and expanded metal lath angles at internal corners.

4. Wood Trim. All interior trim shall be "C" grade fir.

5. Wood Floors. Flooring shall be blind-nailed with steel cut nails

6. Doors. All exterior doors shall be $1^3/_4$-in. fir; interior doors shall be panel $1^3/_8$-in. fir. Standard hardware shall be applied, consisting of hinges and lockset of japanned finish equal to Lockwood economy grade.

7. Windows and Glazing. Windows shall be "packaged," wood, double-hung type, complete with frame, sash, balances, and trim with SS-B glazing. An economy grade of unit similiar to "Huttig" shall be used. Basement sash shall be stock 1-ft 2-in. by 2-ft 9-in. steel projected type with SS-B glazing.

VII. PAINTING

(a) Materials — Exterior

1. For all woodwork on house near range, use two coats of whitewash. On house far range, woodwork shall be ready-mix white, except shutters which shall be light gray, undercoating primer conforming to Federal Specification TT-P-25. Obtain best coverage with one prime coat

2. For coating exposed exterior cinder blocks, a white cement-water paint shall be used conforming to Federal Specification TT-P-21.

(b) Materials — Interior (None)

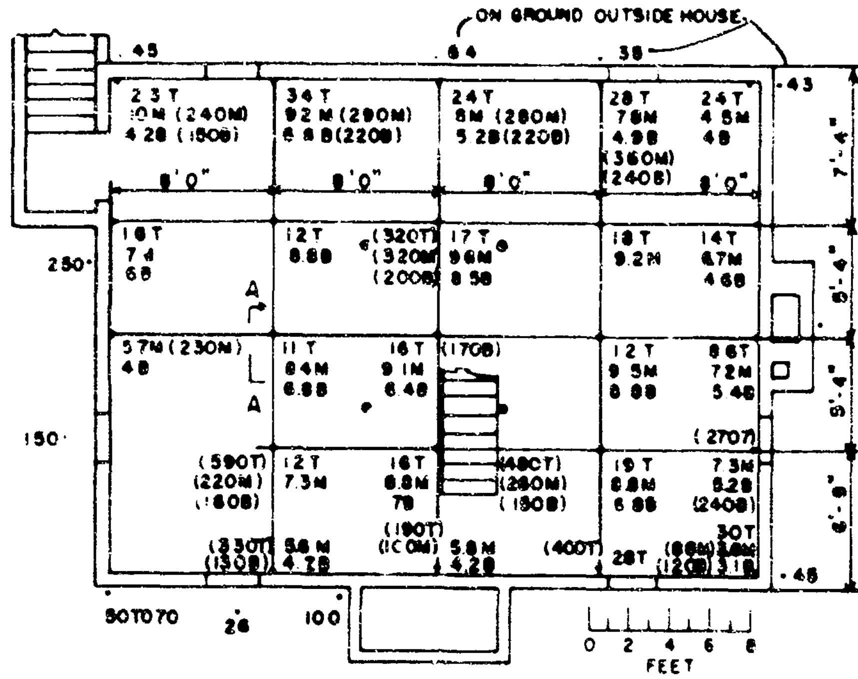
VIII. PLUMBING (None required)

IX. ELECTRICAL WORK (None required)

X. HEATING (None required)

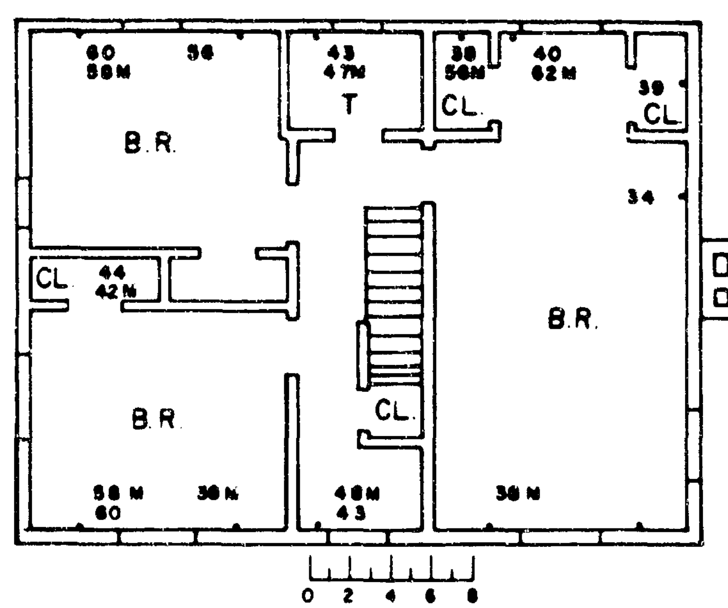
APPENDIX B

DRAWINGS



BASEMENT
BOTH HOUSES

NOTES:
FIGURES DENOTED THUS ( ) ARE READINGS
FOR HOUSE AT 3500 FEET
T = TOP LAYER, M = MIDDLE LAYER, B = BOTTOM LAYER



SECOND FLOOR
HOUSE AT 7500 FT.

NOTE:
BADGES MARKED "M" AR 4'-6"
ABOVE SECOND FLOOR - THER
BADGES ARE ON FLOOR

Fig. B.1—Locati

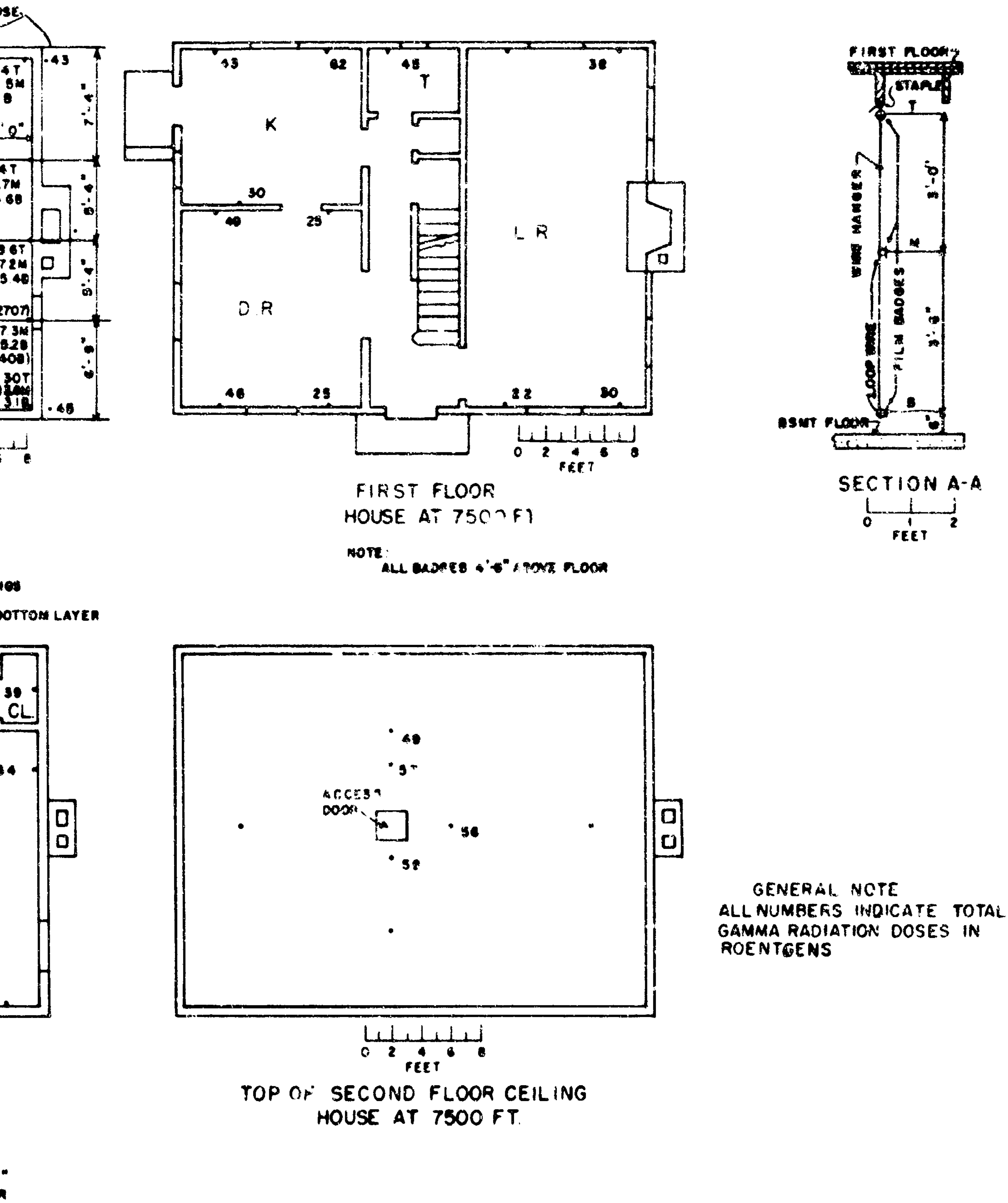


Fig. B.1—Location and total gamma readings of film badges.

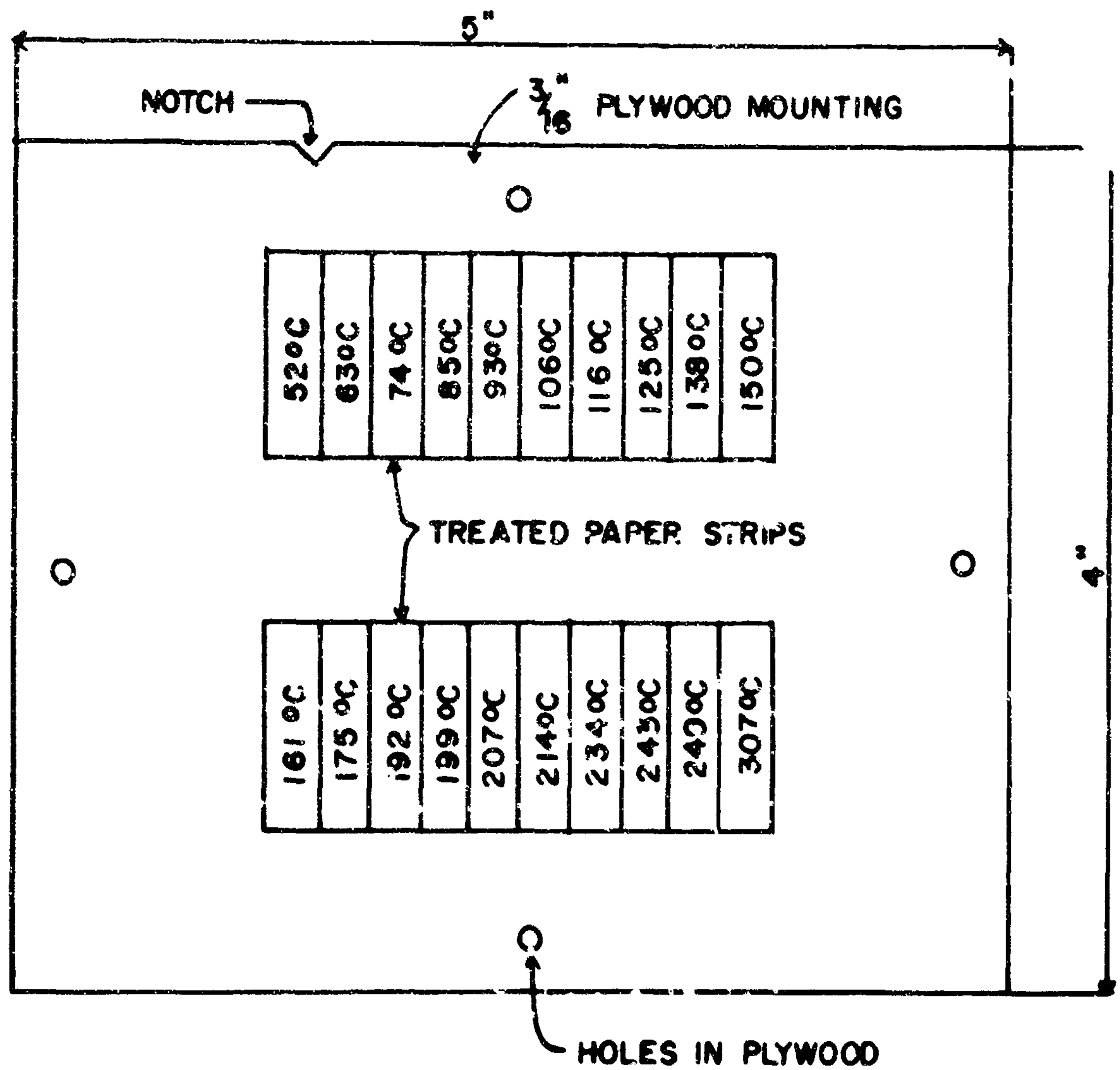


Fig. B.2—Temperature-recording strips.

BL

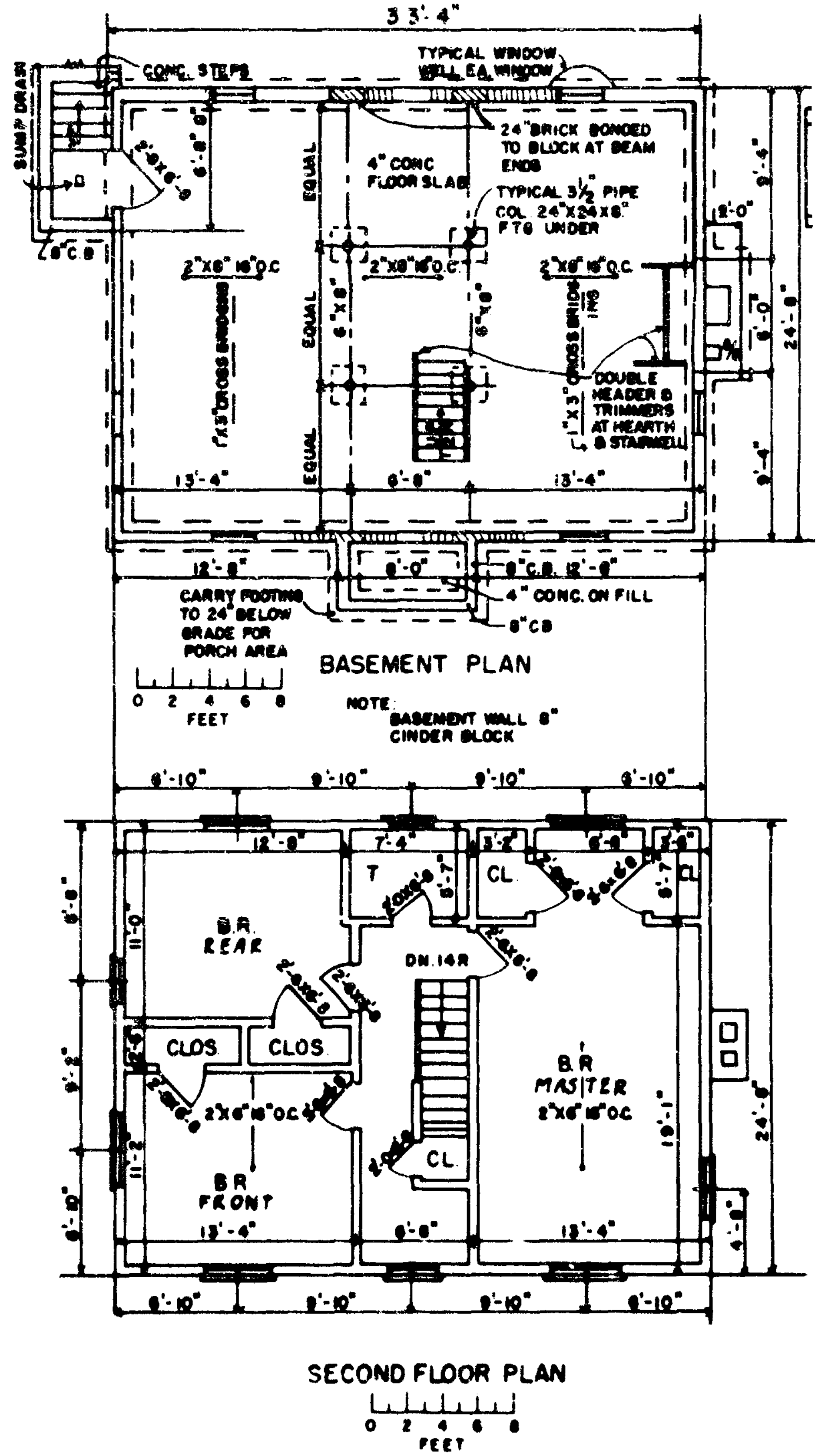
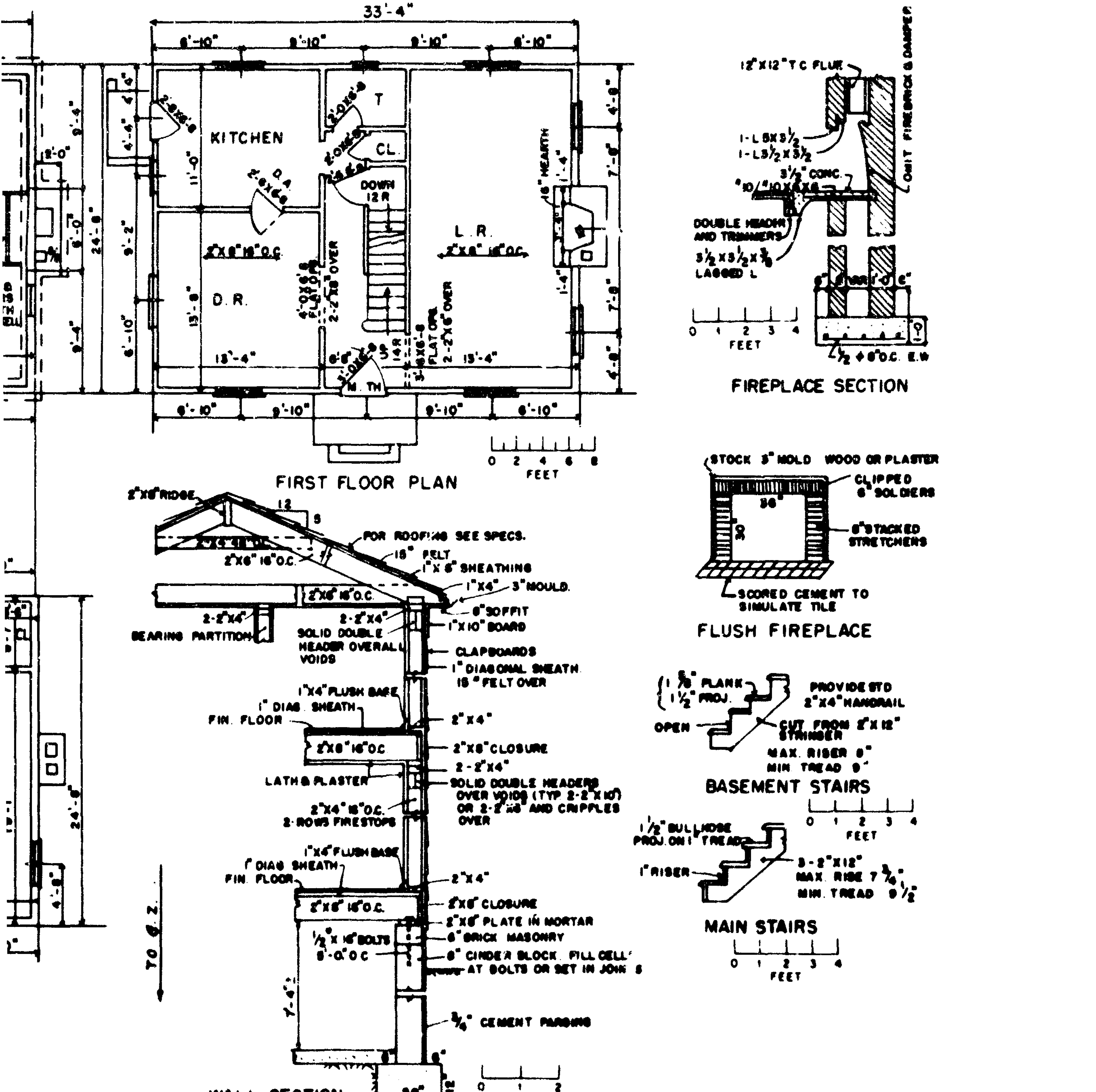


Fig. B.3—Plans and



1.3—Plans and sections of a two-story wood house, FCDA Drawing No. 1.

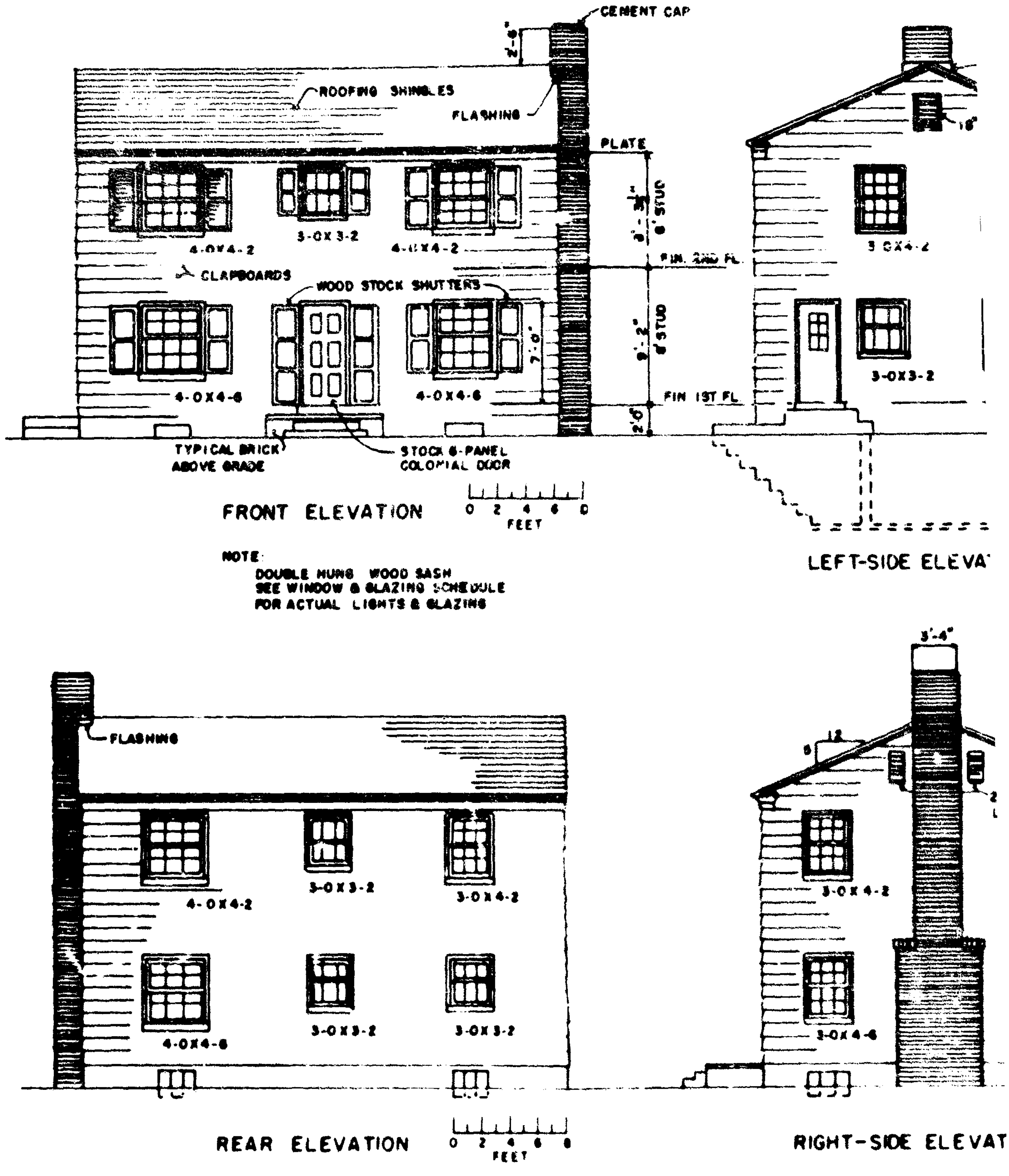
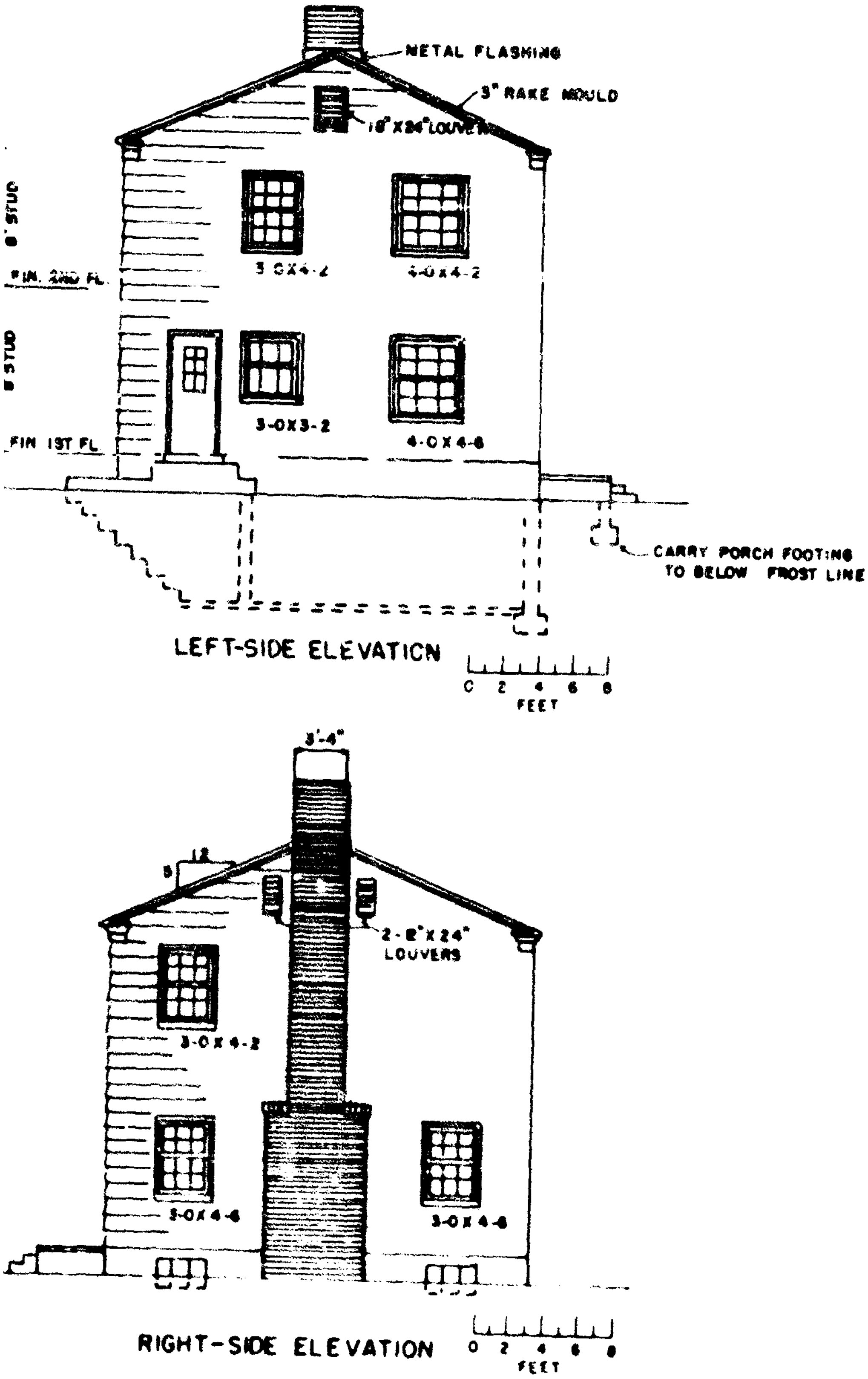


Fig. 8.4—Elevations for a two-story wood house, PCDA Drawing No. 2.

T CAP



wood house, FCDA Drawing No. 2.